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SODIUM BICARBONATE (NAHCOLITE) FROM SEARLES LAKE, CALIFORNIA

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Abstract

Sodium bicarbonate was found in large quantities in a well core drilled below the central salt crust of Searles Lake. It occurs in monoclinic crystals and twins, chiefly in a gaylussite marl. It is suggested that it owes its origin to the interaction of trona and calcium bicarbonate solutions, or formed perhaps during a period when Searles Lake was slightly colder than it is now.

Introduction

The name "nahcolite" has been given to naturally occurring sodium bicarbonate ($NaHCO_3$) by F. A. Bannister,[2] who reported it in an efflorescence from an old Roman underground conduit from hot springs at Stufe de Nerone, near Naples. Later the compound was reported by E. Quercigh[3] as an incrustation in a lava grotto, apparently mixed with thenardite and halite. In neither of these two reported cases was the mineral actually isolated in its pure state and thoroughly investigated. Natural sodium bicarbonate had been reported earlier by P. Walther[4] from Little Mogadi dry lake, 40 kilometers south of Mogadi Lake, in British East Africa, but no confirmatory evidence was given.

The presence[5] of free sodium bicarbonate in the salts of Searles Lake was suspected from the analyses of Searles Lake salts made in the laboratory of the American Potash and Chemical Corporation, Trona, California, and samples were sent to the U. S. National Museum for isolation of the pure mineral, but before this work could be begun, Well No. 34, drilled by this corporation, penetrated rich beds of sodium bicarbonate at various depths from 122 feet to the bottom of the well at 289 feet. The core of this well, as available for examination, began with the bottom of the central salt body of Searles Lake at 81 feet and continued through saline materials to a depth of 289 feet.

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[2] Bannister, F. A.: *Min. Mag.*, **22**, 53–64 (1929).

[3] Quercigh, E.: *Rend. Acad. Sci.* (Naples), **(4)** 7, 19–25 (1937).

[4] Walther, P.: *Am. Mineral.*, **7**, 86–88 (1922).

[5] Letter from Dr. W. A. Gale, Director of Research, American Potash and Chemical Corporation.

The central salt body of Searles Lake consists of alternating beds of soluble saline minerals, chiefly halite, hanksite, trona, glaserite and borax. The insoluble carbonate is chiefly pirssonite ($Na_2CO_3 \cdot CaCO_3 \cdot 2H_2O$) which is almost universally present in these salts in small quantities. The central salt body terminates abruptly in a thin layer rich in trona, borax and northupite ($MgCO_3 \cdot Na_2CO_3 \cdot NaCl$). This is followed by finely laminated shales rich in gaylussite ($Na_2CO_3 \cdot CaCO_3 \cdot 4H_2O$), often predominately this mineral, forming a gaylussite "marl."

Table 1. Occurrence of Nahcolite in Well No. 34
Searles Lake, California

Depth (Feet)	
122–126	Coarse, square prisms, with glassy luster and fair cleavage, in part a pure crystalline mass, in part embedded in microcrystalline northupite. Shows some interstitial borax.
146–147	Coarse, glassy, striated crystals and reticulated twins, with felted, semi-silky interstitial nahcolite. Also a reticulated mat of medium size glassy, striated prisms. Also streaks of small matted crystals in fine crystalline northupite "marl."
170	Pure nahcolite, porous mass of twinned crystals, with a few embedded gaylussite crystals.
178–179	Reticulated mat of prismatic nahcolite crystals, with silky semifibrous areas and embedded larger reticulated twins. Also nests of fine matted crystals, with gaylussite, in marl.
183–186	Almost pure nahcolite; loose porous aggregates of twinned crystals, with vugs lined with glassy individuals. Sometimes indistinctly layered.
204–210 216–217 222–223	Small nests and streaks of reticulated prismatic crystals, with gaylussite, in clay. Not abundant.
228–229	Pure nahcolite as loosely matted glassy prismatic crystals.
259 261–263	Pure, white nahcolite of varying crystal size; fine to medium, granular, with long, silky shreds and more compact areas.
263–272	Predominately a gaylussite "marl," made up of fine crystals of gaylussite. Nahcolite present in long bladed crystals and as scattered arborescent aggregates. Some of the gaylussite is altered to nahcolite, as silky, fibrous pseudomorphs.
272–278	Snowy, fine grained aggregate of nahcolite crystals with semi-silky luster, with pockets of clayey coarser nahcolite.
279–280	Pure, fine granular loosely coherent nahcolite.
281–283	Sparing nests of glassy reticulated crystals in northupite "marl."
283–284	Sparingly, porous, granular nests in marl.

In Well No. 34, the change from pirssonite to gaylussite is not as abrupt as usual, scattered pirssonite persisting 25 feet below the salt crust. The other components of the central salt crust also persisted in scattered bodies below the salt; trona to a depth of 130 feet (but only in the absence of much gaylussite), borax to 115 feet, halite to 120 feet and hanksite only very sparingly to 110 feet. In the place of these ordinary salt crust minerals, two new ones appeared: burkeite ($2Na_2SO_4 \cdot Na_2CO_3$) and nahcolite ($NaHCO_3$). Burkeite was confined to those layers between 94 and 125 feet, usually conspicuously free of gaylussite but with trona and halite abundant, borax occasionally present and hanksite rare.

Nahcolite, on the other hand extends intermittently from 121 to 278 feet, but chiefly from 170 feet to the bottom of the core. At 121 to 122 feet, it occurs in a very thin bed associated with gaylussite, trona, thenardite and northupite, and at 145 to 146 feet with gaylussite, burkeite and thenardite. All other occurrences are in simple gaylussite or northupite marls free of other saline minerals. It is particularly abundant from 169 to 186 feet, from 203 to 210 feet and from 258 to 286 feet.

The individual occurrences of nahcolite in Well No. 34 are given in Table 1.

Besides the various forms of aggregated crystals, nahcolite was also noted in samples from 286 feet as hairy tufts of thin prisms in crystal cavities in marl left by the solution of gaylussite crystals. These hairy tufts, under the microscope, show the typical single and twinned crystal habits of coarser nahcolite.

CHEMICAL PROPERTIES

An abundance of pure material was available for analysis. Clear, glassy crystals were selected from specimen U.S.N.M. No. 102,861. The mineral is easily soluble in water. Analysis by standard methods gave the results recorded in Table 2.

TABLE 2. ANALYSIS OF NAHCOLITE ($NaHCO_3$), SEARLES LAKE, CALIFORNIA

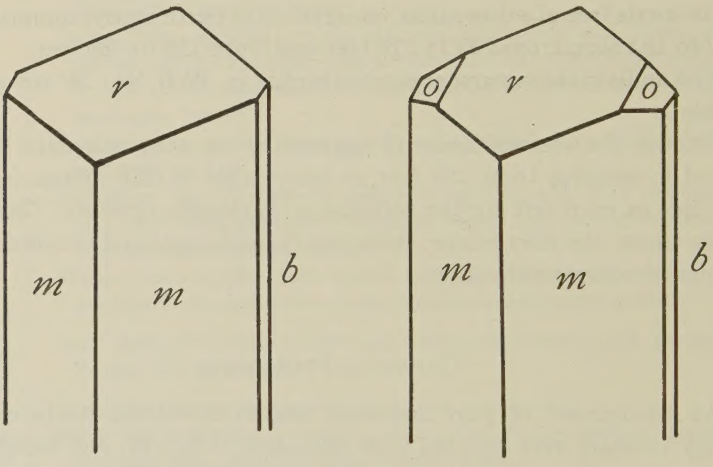
W. F. Foshag, *Analyst*

	Found	Theory
Na_2O	36.74	36.90
CaO	0.20	
$(Fe, Al)_2O_3$	0.16	
CO_2	51.15	52.38
H_2O	10.76	10.72
Insol.	0.82	
	99.83	

Pyrognostics. Nahcolite is soluble in water, yielding a solution alkaline to phenolphalein and to methyl red. It is also soluble in glycerine. The aqueous solution on heating gives off carbon dioxide. Before the blowpipe, nahcolite fuses quietly, yields a white, crystalline bead, and colors the flame intense yellow.

CRYSTALLOGRAPHY

Many of the beds of nahcolite are made up of loosely friable crystal aggregates or porous masses with crystal lined vugs. The largest individuals, sometimes exceeding 2 centimeters in maximum dimension, are reticulated twins, embedded in smaller simpler crystals. Single crystals seldom exceed 1 centimeter in size. Although there is an abundance of crystals, good measurable individuals are rare, due to the prevalence of solution forms on the crystals but, as is often the case in readily soluble minerals, some faces seem unaffected. In the case of nahcolite, the clinopinacoid *b* remains bright, *r*(101) somewhat less so but the prisms and the orthopinacoid are very much rounded. The crystal measurements, therefore, are not of the highest order.



FIGS. 1 and 2. Common habit of nahcolite single crystals, Searles Lake, California.

Simple crystals of nahcolite show little variation in habit. They are commonly prismatic, *m*(110) and *r*(101) are prominent, *b*(010) is narrow (Fig. 1). The pyramid *o*(111) is frequently present (Fig. 2). A termination more rarely met with is *o*(111) and *s*($\bar{1}$01), (Fig. 3).

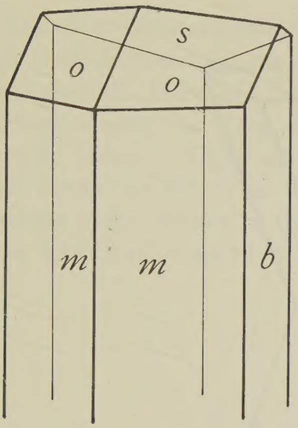


FIG. 3. Unusual termination of *o*(111) and *s*($\bar{1}$01). Searles Lake, California.

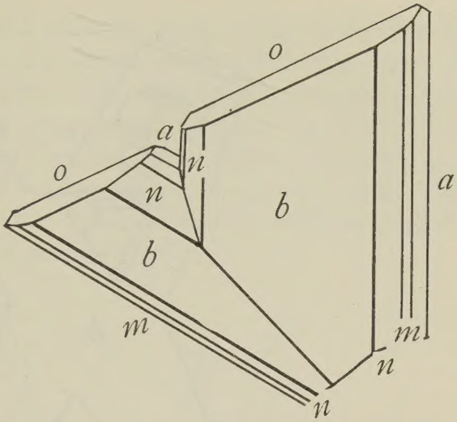


FIG. 5. Acute twin, crystal #4, nahcolite, usually found on complex twinned aggregates, (*b* projection). Searles Lake, California.

Twinning is very common; the twinning plane and the composition plane is *r*(101). Both contact and penetration twins are found, often in combination with each other. Since the twinning is usually repeated, the twinned forms may become extremely varied. As is often the case with twins of this character, they show a decided flattening in the plane perpendicular to the composition plane, in the case of nahcolite the clinopinacoid *b*(010).

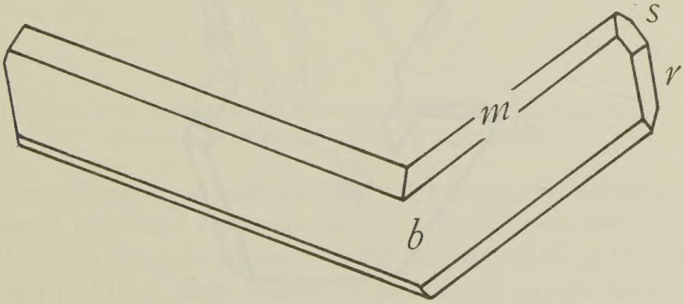


FIG. 4. Obtuse twin, crystal #15 nahcolite. A common habit in fine crystalline aggregates. Searles Lake, California (*b* projection).

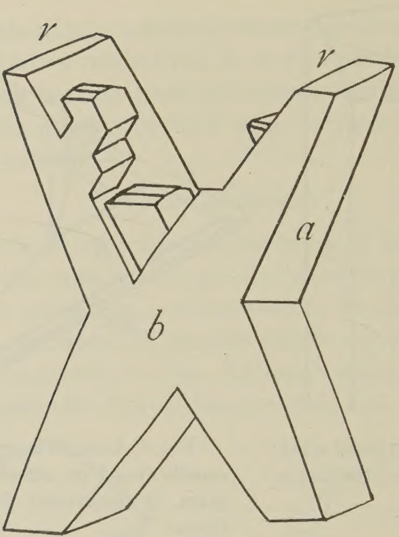


Fig. 6. Penetration twin, crystal #13, nahcolite, with subsidiary twinned individuals. Searles Lake, California (*b* projection).

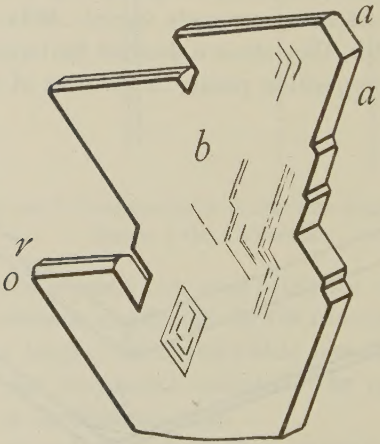
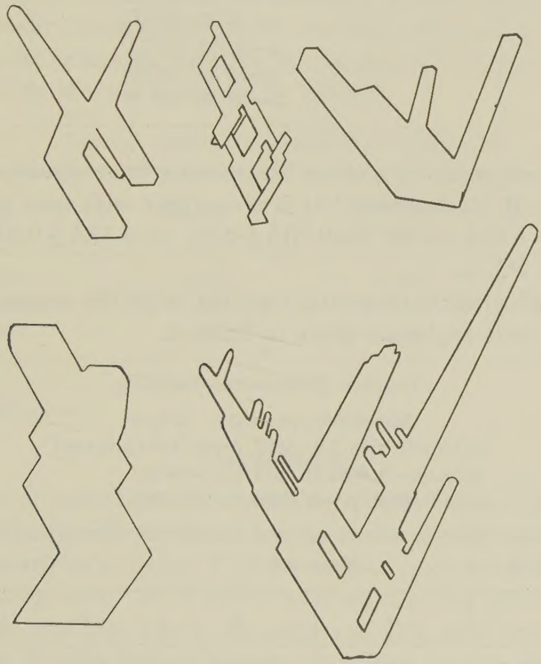


Fig. 7. Flattened repeated twin, crystal #14 nahcolite, frequent habit. Searles Lake, California (*b* projection).

The most common twin habit is a simple obtuse contact twin (Fig. 4) and is often found as complete individuals in the friable aggregates of loose crystals. The acute contact twin (Fig. 5) is usually attached and is, perhaps, simply the acute end of the penetration twins (Fig. 6), that frequently occur as larger individuals embedded in a finer crystalline matrix. Twins, like Fig. 7, are found in nests of loose crystals or in vugs. The possible permutations in these twin combinations are without number, Figs. 8 to 12 showing a few of the general types.



FIGS. 8–12. Camera lucida drawings showing varied twin habits, nahcolite, Searles Lake, California (*b* projection).

The crystallography of artificial $NaHCO_3$ has already been determined by Schabus[6] and found to be monoclinic, with $a:b:c=0.7645:1:0.3582$. $\beta=93° 19'$. The forms noted were: *b*(010), *m*(110), $\omega(11\bar{1})$, *i*(121), *o*(111), *a*(100) and *r*(101). A large number of the natural crystals from Searles Lake were examined, many were mounted for preliminary measurement but only 12 were completely measured because most crystals showed curved faces and could not be accurately adjusted on the goniometer. Since Schabus' measurements are presumably superior to mine, I have calculated the gnomonic elements for nahcolite on the basis of Schabus' elements. The angle measurements on natural nahcolite from Searles Lake are given in Table 3.

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[6] Groth, P.: *Chemische Krystallographie*, **II** Teil, p. 191.

TABLE 3. ANGLE MEASUREMENTS OF NAHCOLITE

Face	No.	Range	Average
$m(110)$	16	$\phi=52°19'–52°53'$	52°35′
$n(120)$	11	$\phi=33°11'–34°12'$	33°30′
$r(101)$	4	$\rho=27°39'–28°00'$	27°48′
$s(\bar{1}01)$	2	$\rho=22°18'–22°22'$	22°20′
$o(111)$	8	$\phi=55°14'–56°10'$ $\rho=32°24'–33°\ 9'$	55°25′ 32°30′

The x-ray elements for sodium bicarbonate have already been determined by W. H. Zachariasen.[7] It is monoclinic with four molecules per unit cell. $a=7.51\text{Å}\pm0.04$, $b=9.70\text{Å}\pm0.04$, $c=3.53\text{Å}\pm0.03$. $\beta=93°19'$. Space group. $P2_1/n$.

The crystallographic elements, together with the measured and calculated two circle angles are given in Table 4.

TABLE 4. NAHCOLITE—$NaHCO_3$

Monoclinic, prismatic $-P2_1/n$
$a:b:c=0.7645:1:0.3582$. $\beta=93°19'$ (Schabus).
$p_0:q_0:r_0=0.4685:0.3576:1$. $\mu=86°41'$.
$p_0'=0.4692$, $q_0'=0.3589$ $X_0'=0.580$.

Letter	Form	Measured		Calculated	
		ϕ	ρ	ϕ	ρ
b	010	0°00′	90°00′	0°00′	90°00′
m	110	52 35	90 00	52 28	90 00
n	120	33 30	90 00	33 11	90 00
r	101	90 00	27 48	90 00	27 48
s	$\bar{1}01$	90 00	$\overline{22}$ 20	90 00	$\overline{21}$ 10
o	111	55 25	32 30	55 45	32 32

Forms found by Schabus on artificial sodium bicarbonate but not found on nahcolite are $i(121)$ ane $\omega(11\bar{1})$.

PHYSICAL AND OPTICAL PROPERTIES

Nahcolite is colorless to white, sometimes gray or buff from included mud. The luster is vitreous, somewhat resinous on the cleavage. Fracture conchoidal. Cleavage: domatic *r*(101) perfect; pyramidal (111) good; pinacoidal *a*(100) distinct.

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[7] *Jour. Chem. Phys.*, **1**, 634–639 (1933).

The mineral is biaxial, negative, $2V=75°$ *ca.* Dispersion is weak, *v* greater than *r*. Cleavage plates (parallel to the perfect cleavage *r*) show a well centered biaxial figure, indicating that the acute bisectrix is normal, or nearly normal to the cleavage. Plane of the optic axis is parallel to *b*(010). $Y=b$. $X\wedge c=27°$.[8] The cleavage fragments bounded by (111) and (100) and lying upon *r*(101) show parallel extinction.

The indices of refraction as determined by the immersion method, with independent determinations on the identical material by Dr. Mark Bandy, and the values for the artificial compound as given by Larsen and Berman and by Merwin are given in Table 5.

TABLE 5. INDICES OF REFRACTION—NAHCOLITE

Foshag	Bandy	Larsen and Berman[a]	Merwin[b]
$\alpha=1.375$	1.378	1.380	1.376
$\beta=1.505$	1.502	1.500	1.500
$\gamma=1.583$	1.583	1.586	1.582

[a] *Loc. cit.*

[b] In Winchell, *loc. cit.*

PARAGENESIS

The origin of nahcolite in the Stufe de Nerone and in a lava tunnel at Vesuvius can be easily explained by the action of CO_2 and water vapor upon thermonatrite or trona. This is a method once much used to manufacture "baking soda." P. Walther believed that the nahcolite of Little Mogadi Lake was also due to the action of CO_2 upon trona, since CO_2 escaped from the playa muds in large quantities. Such an origin might be invoked for the Searles Lake mineral if a sufficient source of CO_2 could be demonstrated.

Sodium bicarbonate, in open solutions, loses CO_2 and passes eventually to trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$). It is this instability of $NaHCO_3$ in solution that led R. Wegescheider[9] to explain its apparent absence in nature. The intimate association of nahcolite, gaylussite, and marls in Searles Lake suggests that it may perhaps owe its presence there to an interaction of trona and calcium bicarbonate (which finds its way into playa basins in small but continuing amounts through the agency of drainage) under conditions that do not allow the escape of carbon dioxide, as in playa muds.

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[8] The value 20° given by Larsen and Berman (The Microscopic Determination of the Nonopaque Minerals. 2d ed., *U. S. G. S., Bull.* **848,** p. 152) is in error. Robson in Winchell (Microscopic Characters of Artificial Minerals: 2d ed. **1931,** p. 199) gives $X\wedge c=27.5°$.

[9] In Doelter: *Handbuch der Mineralchemie,* **1,** 193.

A solution of calcium bicarbonate added to a solution of trona, precipitates abundant calcite, with the formation of sodium bicarbonate according to the reaction.

$$\underset{\text{(trona)}}{NaHCO_3 \cdot Na_2CO_3 \cdot 2H_2O} + Ca(HCO_3)_2 \rightarrow \underset{\text{(nahcolite)}}{3NaHCO_3} + \underset{\text{(calcite)}}{CaCO_3} + 2H_2O.$$

Or it may produce gaylussite after the reaction

$$\underset{\text{(trona)}}{2(Na\ HCO_3 \cdot Na_2CO_3 \cdot 2H_2O)} + Ca(HCO_3)_2 + H_2O \rightarrow \underset{\text{(nahcolite)}}{4NaHCO_3} + \underset{\text{(gaylussite)}}{Na_2CO_3 \cdot CaCO_3 \cdot 5H_2O}.$$

Gaylussite is stable in strong trona solutions at ordinary temperatures. Such a reaction would, then, explain the presence of sodium bicarbonate.

There is a second and interesting possibility that may be suggested. In the system Na_2CO_3–$NaHCO_3$–H_2O, trona is not stable below 21.26°;[10] $NaHCO_3$ (nahcolite) and $Na_2CO_3 \cdot 10H_2O$ (natron) are the stable phases. The temperature of the deep brines at Searles Lake is 22.5°. The position of the nahcolite in the lower beds of Searles Lake suggests the possibility that these salts were deposited during the Pleistocene period of glaciation, when, presumably, the waters were somewhat colder than they are today. A temperature drop of slightly more than 1° would bring about the deposition of nahcolite.

The writer desires to express his thanks to Dr. W. A. Gale of the American Potash and Chemical Corporation, for calling this interesting occurrence to his attention, and for transmitting to the U. S. National Museum the nahcolite bearing portion of the core.

[10] Hill and Bacon: *Jour. Am. Chem. Soc.*, **49**, 2487–2495 (1927).

THE SHALLOWATER METEORITE; A NEW AUBRITE

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Abstract

The Shallowater meteorite was found near Shallowater, Lubbock County, Texas. It is an aubrite made up of enstatite (En_{100}) 81%, fosterite (Fo_{100}) 5%, oligoclase ($Ab_{83}An_{17}$) 2%, iron-nickel ($Fe_{93}Ni_7$) 9%, troilite 1½%, miscellaneous 1½%. The silicates are remarkably free from iron. It is suggested that this meteoric material is the result of crystallization from a melt and that the iron-nickel and troilite are later.

Introduction

The Shallowater meteorite was brought to my attention by Mr. Harvey H. Nininger of the American Meteorite Laboratory, who obtained it from Mr. B. O. McWhorter of Lubbock, Texas, who marketed the Estacado stone many years ago. Mr. Nininger has given me the following interesting account of its discovery:

> In 1933, I spent some time with Mr. McWhorter showing him various types of meteorites and urging him to keep on the lookout for specimens. We exchanged letters frequently thereafter. In 1936 during May, he was visiting with the man who then lived on the old ranch once owned by Mr. McWhorter near Shallowater, Texas. He showed Mr. Mullican a number of specimens which I had left with McWhorter for that purpose. Mullican thought at the time that he remembered seeing such a stone but said nothing. A few weeks later while working on the farm he came across the meteorite and reported it to McWhorter who in turn reported it to me. The stone was found on the S.E. quarter of Section 7, Block D 5, Lubbock County, Texas. This is about 3 miles northwest of Shallowater. Quite a thorough search has been conducted in the community but no other material has as yet shown up. The weight of the stone was 4750 grams.

The Shallowater meteorite as received was a polyhedral mass measuring 16 cm.×14 cm.×12 cm. The crust is now oxidized and badly iron stained but where it is best preserved shows a pimply surface. Where the corners or edges are broken, the coarse cleavage of the enstatite is easily evident. The color of the mass is now light chocolate brown, but this color is due to a tenuous infiltration of limonite.

The meteorite is extremely coarsely crystalline. The longest individual noted measured 4.5 cm. by .5 cm., while the largest equidimensional grain measured 2 cm. by 2.5 cm. or 5 $cm.^2$ in area. Many of the grains are long lath-like individuals but with very irregular boundaries, the whole presenting a broad reticulating texture. Many of the crystals show iron oxide introduced along the cleavages during oxidation and weathering. Under the binoculars the clearer unstained grains are colorless, transparent to translucent and glassy. The enstatite, when cleaned of limonite by acids, becomes pure white in color. Cleavage is pronounced, giving the cut or polished surfaces a mottled silky sheen, and is conspicuous in thin section.

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Occasional small inconspicuous vugs are present, showing a few rough faces of the bounding enstatite, some limonite and rarely a rounded fosterite grain, but no well defined crystals.

Unlike other aubrites and diogenites the Shallowater meteorite is not fractured or brecciated but is entirely made up of a firm, compact aggregate of enstatite individuals.

Except for the enstatite no mineral is evident except the small, irregular grains of nickel iron and troilite. Thin sections, however, reveal the presence of a little feldspar and fosterite.

MINERALOGY

Enstatite. The Shallowater meteorite is essentially a monomineralic rock, consisting of enstatite, very coarsely crystalline in texture. On the broken surfaces the enstatite individuals can readily be distinguished by their prominent cleavage; on the polished faces by a prominent sheen, due to this cleavage. The crystal cross sections are, in general, coarse lath-like and the texture an irregular mosaic of these laths.

The color of the enstatite in the mass is gray-brown, but this color is induced by the minute films of secondary iron oxide introduced along the cleavage planes during oxidation and weathering. Under the binoculars the clear, unstained grains are colorless, glassy and transparent to translucent. The enstatite when cleaned of limonite by acids becomes pure white in color.

Cleavage is prominent both megascopically and microscopically. Measurement of cleavage fragments on the goniometer gave indifferent results but indicated the presence of the normal prismatic cleavage of 88° and 92°.

The optical properties of the Shallowater enstatite are given below: Biaxial, positive, $2V=54\frac{1}{2}°$.[2] Dispersion weak, $r>v$. Extinction parallel, but undulatory and other extinction anomalies common, including a hackly pattern suggestive of twinning. Plane of the optic axes is parallel

TABLE 1. INDICES OF REFRACTION OF ENSTATITE, SHALLOWATER, METEORITE

Foshag	Glass	Hess	$MgSiO_3$[3]
$\alpha=1.653$	1.647		1.651
$\beta=1.656$	1.649		
$\gamma=1.660$	1.658	1.6592	1.660

[2] Determination by Harry H. Hess.

[3] Bowen, N. L., and Schairer, J. F.: *Am. Jour. Sci.*, **29**, 199 (1935).

to the cleavage, with Z = *c*. No intergrowth of monoclinic pyroxene with the enstatite, so common in terrestrial rocks, was observed.

Indices of refraction, by the immersion method, are given in Table 1.

Inclusions are fairly abundant consisting of (1) long rod-like cavities parallel to the cleavage direction, often with included bodies of unrecognizable character, and (2) rounded or irregular inclusions, sometimes arranged in lines parallel to the cleavage direction, also with small included bodies.

The pure enstatite separated from the other constituents by a magnetic removal of the iron, and by heavy solution; and cleaned of limonite by dilute hydrochloric acid, gave upon analysis, the composition given in the table below.

ANALYSIS OF ENSTATITE, SHALLOWATER METEORITE
W. F. Foshag, *Analyst*

SiO_2	59.92
Al_2O_3	None
Fe_2O_3	None
FeO	0.38
MgO	39.51
CaO	0.32
Na_2O	None
	100.13

This analysis, together with the indices of refraction indicate an enstatite of almost theoretically pure composition. Such pure enstatites are not found in terrestrial rocks but are characteristic of aubritic meteorites.

Fosterite. This mineral is not apparent to the eye but can be found sparingly in thin sections. It occurs as equant or subhedral grains sometimes with indications of crystal outline, poikilitically embedded in enstatite, from which it can be distinguished by its higher birefringence and poor cleavage. In contrast to oligoclase, which is quite irregular in shape, the fosterite is more equidimensional and quite round. In Fig. 1, characteristic grains of fosterite (F) are shown, the middle one being quite spherical in shape.

Fosterite was also found as rounded, glassy crystals in a few of the cavities of the meteorite from which they could be detached for further examination. These grains do not exceed a mustard seed in size. They are clear, glassy, rounded grains, without inclusions, somewhat flattened and with indications of crystal facets on their surfaces. They suggest the

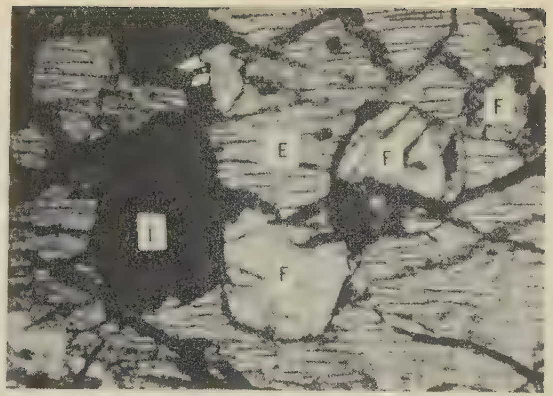

FIG. 1. Fosterite (F) and nickel-iron (I) in enstatite (E). Shallowater meteorite (×50).

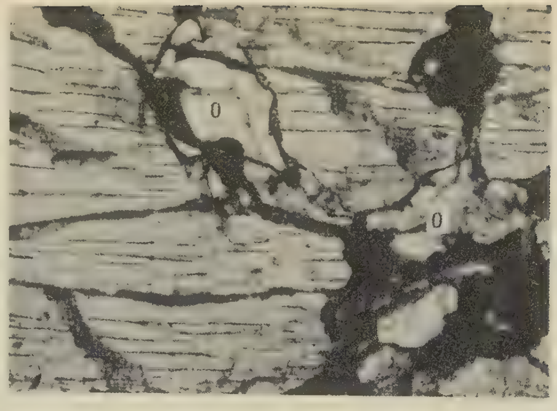

FIG. 2. Oligoclase (O) in enstatite. Shallowater meteorite (×50). The dark veins in 1 and 2 are secondary limonite stains.

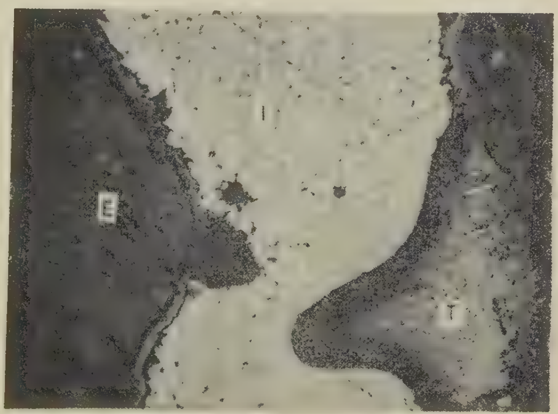

FIG. 3. Nickel-iron (I) etched with nitol, showing Neumann lines and pearlitic structure. Troilite (T) and enstatite (E). The border around the nickel-iron and the

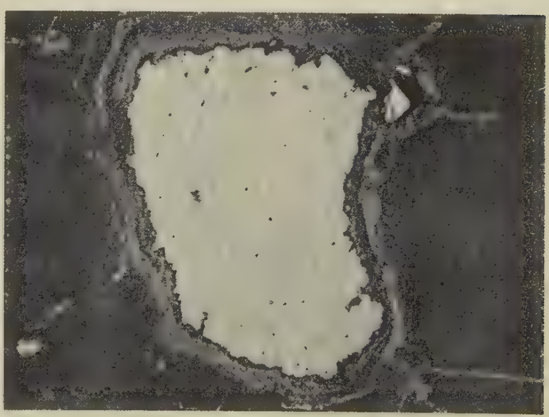

FIG. 4. Nickel-iron in enstatite, showing pearlitic structure. The border about the nickel-iron is due to oxidation (×100). Shallowater meteorite.

olivine grains described and figured by G. Rose[4] and N. V. Kokscharov.[5] The optical properties of these grains are as follows:

Biaxial, positive, with a large optical angle (2V nearly 90°). $\alpha=1.635$, $\beta=1.650$, $\gamma=1.670$. These grains have two prominent parallel facets and α(X) is normal to this face. From the optical orientation of fosterite this face is identified as the brachypinacoid (*b*).

The indices of refraction of pure fosterite are, according to Bowen and Schairer:[6] $\alpha=1.6359$, $\beta=1.6507$, $\gamma=1.6688$. The fosterite of the Shallowater meteorite is, then, pure magnesium silicate.

Oligoclase. Feldspar is not evident to the naked eye but is observable in thin sections under the microscope and was found sparingly in the insoluble portion, from which it was separated by heavy solution. The material so recovered is in clear and glassy fragments, very rarely showing crystal form. A single small crystal showed the forms: $a(100)$, $b(010)$, $c(001)$ and $x(\bar{1}01)$, with $c\wedge x$, measured under the microscope, of 52°.

The indices of refraction of this feldspar indicate little or no variation in its chemical composition. $\alpha=1.537$, $\beta=1.541$, $\gamma=1.545$. This corresponds to oligoclase of the composition $Ab_{83}An_{17}$.

Under the microscope the oligoclase is seen as small irregular grains embedded within the enstatite crystals (O in Fig. 2) or associated with rounded fosterite grains. It is clear and glassy and rarely shows inclusions. In the crystal mentioned above, long rodlike cavities or rows of small irregular cavities formed lines parallel to the face $x(\bar{1}01)$ and to the base $c(001)$. Occasional grains show a faint, very fine polysynthetic twinning. An unusual feature is that oligoclase grains within the same general area often come to extinction simultaneously, even though they are quite widely separated. Usually all the oligoclase grains enclosed in a single enstatite individual extinguish together.

Tridymite or cristobalite was sought for in the heavy solution fraction but was not found.

Nickel-iron. The nickel-iron forms irregular masses, which, in rare cases reach 3 mm. in maximum diameter. The iron masses often show deep semicircular embayments, where they are in contact with rounded rods of enstatite. There are occasional cavities in the meteorite, into which protrude such rounded grains of enstatite. These cavities resemble in size and shape the iron masses, and they have the appearance of cavities that have escaped a filling of iron. Irregular grains of iron occasionally are found embedded in the enstatite.

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[4] Rose, G.: *Abhandl. Königl. Acad. Wiss., Berlin*, 73–75, 1864 (for 1863).

[5] Kokscharov, N. V.: *Mem. Acad. Imp. Sci. St. Petersburg*, 7th ser., **15**, 1–40 (1870).

[6] Bowen, N. L., and Schairer, J. F.: *Am. Jour. Sci.*, **29**, 196 (1935).

The nickel-iron and troilite grains are usually distinct but occasionally the two minerals (Fig. 3) show an area of troilite in association with iron.

Since the nickel-iron is sparsely distributed in the meteorite, a small sample sufficient only for a nickel determination was separated and cleaned for analysis. Nickel was determined by dimethylglyoxime from a solution in which the iron was retained in solution by tartaric acid. This method has proven to be the best for simple nickel determinations. The results of this determination gave 6.70 per cent nickel, insoluble (enstatite) 1.91 per cent. On the basis of a silicate free sample the nickel content would be 6.83 per cent. This conforms well with Prior's[7] theory that low-iron silicates are associated with low nickel irons, in this case iron free enstatite and fosterite with nickel-iron almost the composition of kamacite.

The structure of the nickel-iron shows, upon etching with 10% nitol, two sets of figures; one, straight lines, similar to and perhaps identical with Neumann lines (Fig. 3); and a second pattern resembles that of pearlite (Figs. 3 and 4). The straight etch lines I would interpret as the cleavage lines of α-iron (kamacite) but for the second pattern, I offer no explanation.

Vivianite. A very few of the small cavities of the meteorite are filled with a compact dark gray-blue mineral of a semi wax-like consistency. Under the microscope this mineral is very fine grained, sometimes rather shredded. The large shreds show a strong pleochroism in deep blue and pale olive and have a mean index of refraction of less than 1.655. Chemical tests show the presence of iron and phosphorus. The mineral is probably vivianite. It appears to be a secondary product due to the weathering of some original phosphide or phosphate mineral.

MINERAL COMPOSITION

A characteristic sample of the meteorite of almost ten grams was crushed and digested in nitric acid. In the insoluble residue, separated silica was redissolved by digestion with sodium carbonate. The soluble portion was analyzed with the following results:

ANALYSIS OF THE SHALLOWATER METEORITE

Soluble portion

SiO_2	2.90 per cent
Al_2O_3	0.25
MgO	2.74
CaO	0.21
Na_2O	0.21
K_2O	0.04
Cr_2O_3	0.05

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[7] Prior, G. T.: *Min. Mag.*, **18**, no. 83, 26–44 (1916).

Fe[1]	9.05
Ni	0.60
S	0.45
P[2]	0.19
	16.69 per cent

[1] Includes also Fe as oxides in limonite, chromite, vivianite, etc.

[2] Probably as P_2O_5 in vivianite, etc.

No determination was made of the amount of oligoclase present in the meteorite but it was estimated at about 2 per cent.

The mineralogical composition of the Shallowater meteorite can be given as follows:

MINERALOGICAL COMPOSITION OF THE SHALLOWATER METEORITE

Enstatite (En_{100})	81 per cent
Fosterite (Fo_{100})	5
Oligoclase ($Ab_{83}An_{17}$)	2
Iron-nickel ($Fe_{93}Ni_7$)	9
Troilite	1½
Miscellaneous	1½
	100 per cent

ORIGIN

The silicate portion of the Shallowater meteorite, like the terrestrial enstatolites and other similar pyroxenites, is difficult to interpret in the light of the equilibrium relations found in the system MgO-SiO_2 as worked out by N. L. Bowen and Olaf Anderson[8] and the system MgO-FeO-SiO_2 as worked out by N. L. Bowen and J. F. Schairer.[9] Clinoenstatite is the stable form at high temperatures; its inversion to enstatite takes place at 1140°. From the data furnished by these equilibrium studies it is not to be expected that an orthorhombic enstatite of the nature of the Shallowater meteorite should form directly by crystallization of its melt, or magma, without the intervention of the monoclinic form. For terrestrial enstatolites, Bowen and Schairer have been led to conclude that these rocks are the result of local accumulations of crystals of one kind from a magma of complex constitution.

Yet the extraordinarily coarse crystallinity of the enstatite, the total lack of any evidence of its derivation from a pre-existing form, and the reticulated fabric of the crystals, as well as the relation of the fosterite to the enstatite, suggest that this meteorite may, indeed, be a direct crystallization from a magma. The evidence of orthorhombic pyroxenes in

[8] Bowen, N. L., and Anderson, Olaf: *Am. Jour. Sci.*, **37**, 487–500 (1914).

[9] Bowen, N. L., and Schairer, J. F.: *Am. Jour. Sci.*, **29**, 151–217 (1935).

the chondrules of chondritic meteoric stones, too, should not be overlooked. There is perhaps some mechanism that has as yet escaped attention by which orthorhombic pyroxenes can result directly from melts.

The origin of the nickel-iron involves further difficulties in interpreting the origin of this rock. The association of iron-nickel and the iron-rich sulfide, troilite (FeS) with iron free silicates that normally contain iron, is an extraordinarily anomalous one. Two explanations suggest themselves: (1) that the system during crystallization was deficient in oxygen to the extent that, while sufficient to satisfy the magnesium, none was available for even a trace of the iron; or (2) that the iron and the troilite were introduced after the crystallization of the magnesium silicates. The first calls for an extraordinarily fine balance in the oxygen supply and since this condition is not peculiar to the Shallowater meteorite, but exists in other aubrites as well, it appears quite beyond the laws of chance that such a condition could exist in a number of distinct cases.

On the other hand there are suggestions that the nickel-iron and the the troilite were later introductions. The stone contains a number of small cavities, of much the size and shape of both the iron and troilite masses, and, although they were very carefully examined, no indications could be detected that they had ever been filled. This problem of the relation of nickel-iron to silicates in stony meteorites is one that deserves considerable attention.

The writer wishes to thank Mr. Stuart H. Perry of Adrian, Michigan, for the 2 excellent photomicrographs of the nickel-iron.

CLASSIFICATION OF MINERALS OF THE TYPE $A_3(XO_4)_2 \cdot nH_2O$ (Concluded)

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(*Continued from page 753*)

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THE $A_3(XO_4)_2 \cdot 4H_2O$ FAMILY

This family is composed of the triclinic group—parahopeite and anapaite; the monoclinic member—phosphophyllite; and the orthorhombic member—hopeite. The relations between the unit cells of phosphophyllite and hopeite are simple and are given in the description of the former. Parahopeite and anapaite have very similar unit cells, their differences being due solely to the variation in cation content. The relation between the cells of the triclinic members and the monoclinic and orthorhombic members is not clear.

The addition of one or more molecules of water to each crystallizing molecule must be accompanied by a completely new bonding arrangement, for there is no recognizable relation between the unit cells of the members of the various families and there is no single factor of the unit cells which varies with the water variation. Thus it is impossible to relate the unit cells of the various families, although there is a definite relation between the cell volumes and the number of water molecules.

Within this family the optics vary over a narrow range, and the optic sign changes from positive to negative as the crystal system changes from triclinic to monoclinic and orthorhombic symmetry systems. The hardness varies from about $2\frac{1}{2}$ in hopeite to about $3\frac{3}{4}$ in parahopeite. The specific gravity reflects the cation content and the crystal system. The heavier ions, of course, raise the specific gravity, and the higher symmetry tends to be accompanied by a decrease in specific gravity. The cell volumes in this family increase or decrease with the varying ionic radii of the cations (all of the minerals of the family being phosphates, the anion effect is constant) and with the symmetry, the higher symmetries being accompanied by multiple cell volumes. These multiple volumes, when divided by the number of molecules in the unit cell are actually larger per unit than the comparable lower symmetry cells, which is in conformity with the occurrence of lower densities with higher symmetries.

Parahopeite. The physical and chemical properties of parahopeite were adequately described by Spencer (1908). Spencer made no attempt to give a thorough treatment of the crystallography, but this was done later by Ledoux, Walker, and Wheatley (1919). L. LaForge (private communication), using the measured angles of these authors, calculated somewhat different elements which were more consistent with the majority of their measurements. LaForge's morphological values are given in Table 7.

The only new data developed in the present work are the results of x-ray investigations. The value for $a:b$, determined by Ledoux, Walker, and Wheatley is actually slightly closer to the $a_0:b_0$ value determined in this study, but the $b:c$ value of LaForge is decidedly closer to the $b_0:c_0$ x-ray value than that of the other authors.

The x-ray work consisted of rotation, 0-layer-line, and 1-layer-line pictures about $c[001]$ and a 0-layer-line picture about $b[010]$. The measured specific gravity of 3.307 on 21 mg. is practically identical with the value of 3.31 obtained by Spencer, using a pycnometer, on 889 mg.

Anapaite. The crystallography of anapaite (tamanite of Popoff, 1903) has been treated adequately by Palache (1933). One change has been necessitated, however, in order that the c-axis might be shorter than either the a or b-axes, This is brought about by interchanging Palache's a and c-axes, making his perfect cleavage $a\{100\}$ the $c\{001\}$ in the new setting. The transformation from the setting of Palache to the one adopted here is:

$$00\bar{1}/010/\bar{1}00$$

The cell resulting from this transformation is strictly comparable with that obtained by x-ray means.

TABLE 7. DATA OF THE $A_3(XO_4)_2 \cdot 4H_2O$ FAMILY

Mineral	Parahopeite	Anapaite	Phosphophyllite	Hopeite
Composition	$Zn_3(PO_4)_2 \cdot 4H_2O$	$Ca_2Fe(PO_4)_2 \cdot 4H_2O$	$Zn_2(Fe, Mn)(PO_4)_2 \cdot 4H_2O$	$Zn_3(PO_4)_2 \cdot 4H_2O$
Crystal System	Triclinic	Triclinic	Monoclinic	Orthorhombic
Crystal Class	Pinacoidal	Pinacoidal	Prismatic	Dipyramidal
Space Group	$C_i^1 - P\bar{1}$	$C_i^1 - P\bar{1}$	$C_{2h}^5 - P2_1/c$	$D_{2h}^{16} - Pnma$
a_0	5.755	6.41	10.23	10.64
b_0	7.535	6.88	5.08	18.32
c_0	5.292	5.86	10.49	5.03
$a_0:b_0:c_0$	0.7638:1:0.7023	0.9317:1:0.8512	2.0138:1:2.0650	0.5808:1:0.2745
α	93°17½′	101°34½′		
β	91°55′	104°05½′	120°15′	
γ	91°19′	71°03½′		
Morphology $a:b:c$	0.7747:1:0.7017	0.9401:1:0.8575	2.026:1:2.079	0.5761:1:0.2741
Cell Volume	228.83	234.86	470.92	980.47
Cell Contents	1 molecule	1 molecule	2 molecules	4 molecules
Sp. G. Meas.	3.307	2.812	3.130	3.04
Sp. G. Calc.	3.304	2.796	3.144	3.08
Cleavages	(010)	(001) (010)	(100) (010) ($\bar{1}02$)	(010) (100) (001)
	Good	Perfect Good	Perfect Distinct	Perfect Good Poor
Hardness	3.75	3.5	3.5	2.5–3
Optical Sign	+	+	−	−
2V	90° ca.	53° ±	50°	37°
$r:v$	$r<v$	$r>v$ perc.	$r>v$ perc.	
Indices α	1.614	1.602	1.595	1.589
of β	1.625	1.613	1.614	1.598
Refraction γ	1.637	1.649	1.616	1.599
		ϕ ρ		
X		−119° 81°		a
Y		147° 70°	to a = 50°	c
Z		−6° 21°	b	b
Locality	Broken Hill, S.W. Rhodesia	Taman Peninsula	Pleystein	Broken Hill, S.W. Rhodesia

The x-ray data, using one of the crystals studied by Palache, were obtained from rotation and 0-layer-line pictures, using the three principal directions of the lattice as rotation axes. Calculation of λ, μ, and ν gave almost identical values with those obtained by Palache, so his values were used in the calculations. The calculated specific gravity (2.796) of pure $Ca_2Fe(PO_4)_2 \cdot 4H_2O$ compares favorably with the measured value (2.812).

The composition of anapaite is practically the same as that of fairfieldite except for the addition of two water molecules to the simplest molecular composition of the latter. Some similarity in other properties might be expected, but the properties in general are much more like those of the other members of the family rather than like those of fairfieldite. Each of the cell edges has been lengthened, but not uniformly. The resultant volume is 37.66 cubic ångstroms greater, which gives the volume of one water molecule in the structure as 18.83 cubic ångstroms, which is very close to the average value of 19 cubic ångstroms derived from Table 1. The best cleavage in both cases is $c\{001\}$, and each has a good cleavage parallel to $b\{010\}$. The hardness does not seem to have been affected, but the specific gravity is notably less. There is a marked change in the optical orientation and a lowering of the indices of refraction.

Messelite. This mineral has been found in only one locality, Messel in Hessen, Germany, associated with dark, carbonaceous material. Crystals are abundant in the material, but they are highly altered and etched. A complete morphological treatment is impossible, since there are but two forms on the crystals, and the large one of these is highly etched on all of the crystals. The only published work on the mineral is the original, short description by Muthmann (1889). He gives the angle between these two forms as 42–43 degrees. My x-ray study proves the angle to be about 46 degrees; the optical goniometer measurements are quite unreliable.

Muthmann's analysis gives $2\frac{1}{2}$ molecules of water in the simplest formula. As the triclinic species of the chemical type have but one molecule to the unit cell and as one-half of a molecule of water is impossible, except statistically, it seemed wise to have another analysis made on the type material. This was done by Mr. F. A. Gonyer with the results given in Table 8.

Gonyer's analysis gives the simplest formula as $Ca_2(Fe, Mg)(PO_4)_2 \cdot 2\frac{1}{4}H_2O$. This fits no better into the theory of this paper than Muthmann's formula. The small but notable differences between the two analyses, as shown in columns 1 and 2, would seem to indicate the possibility of considerable variation in composition from sample to sample. That this might well be so is indicated in the discussion which follows.

A powder picture of the material was almost identical with that of

TABLE 8. COMPOSITION OF MESSELITE

	1	2	3	4
P_2O_5	37.72	38.75	.2728	1.000
FeO	15.63	17.27	.2404	0.881
CaO	31.11	29.47	.5255	1.926 } 3.077
MgO	1.45	2.97	.0737	0.270
H_2O	12.15	10.89	.6050	2.218
Insol.	1.40	.87		
	99.46	100.22		

1. Analysis by W. Muthmann (1889).
2. Analysis of messelite from Messel in Hessen. Analyst, F. A. Gonyer.
3. Molecular proportions.
4. Molecular proportions with P_2O_5 equal to 1.

collinsite, belonging to the $2H_2O$ family, but rotation and Weissenberg studies gave an unit cell almost identical with that of anapaite, which belongs to the $4H_2O$ family. On the Weissenberg pictures were many extraneous spots which did not fit into any projected reciprocal lattice pattern. The specific gravity was between that of collinsite and fairfieldite and much higher than anapaite. The listed indices of refraction were much too high for anapaite and somewhat too high for the fairfieldite group.

The reason for these ambiguities lies in the extensive alteration of the mineral. Under crossed nicols no complete extinction could be obtained due to this alteration except in very limited regions of the crystals. The altered portions had a mean index of 1.66 to 1.67, while the unaltered sections had indices comparable with those of anapaite. Thus, messelite, as analyzed, is composed of two substances, one of which is essentially anapaite, and the other is essentially collinsite.

According to Palache's work on anapaite (1933), $m\{110\}$ (his setting) is the largest form on the crystals. The angle between $m(110)$ and $r(101)$ is 45°29′, which is very close to the value of 46° determined by x-ray analysis for the angle between the two faces found on messelite. If this correlation be correct, the axis of rotation of the messelite crystal would be equivalent to the $[1\bar{1}\bar{1}]$ axis of anapaite. It is possible to calculate the periodicity along $[1\bar{1}\bar{1}]$ (Wolfe, 1937). The value obtained is 9.81Å as compared with the measured rotation value for messelite of 9.80Å.

When the cell edge lengths for Messelite obtained from pictures with $[1\bar{1}\bar{1}]$ as the rotation axis were transformed to obtain the shortest periodicities in the lattice, the following results were obtained as compared with anapaite.

Messelite	Anapaite
$a_0=6.59$	6.41
$b_0=6.81$	6.88
$c_0=5.76$	5.86
Cell Vol. = 232.5Å	234.9Å

In the crystals used for Weissenberg study the collinsite portions were not oriented relative to the axis of rotation, but the anapaite parts were. Thus, anapaite results were obtained. The extraneous spots observed on the Weissenberg films were no doubt due to the unoriented collinsite material. There was probably seven times as much of this as of the anapaite material, which explains the collinsite powder pictures obtained from messelite. On a sample separated by gravity, a powder picture was obtained which showed very faint lines which could be referred only to anapaite.

All lines of evidence, therefore, point to the fact that messelite is a mixture of an unaltered material, anapaite and an altered material, collinsite. Messelite, therefore, cannot be considered a mineral species.

Phosphophyllite. This mineral, found only near Pleystein in the Oberfalz, Bavaria, has been amply described by Laubmann and Steinmetz (1920), Steinmetz (1926), Palache and Berman (1927), and Kleber (1935).

Palache and Berman chose a different orientation and unit than did the first two authors, the transformation formulae being:

Laubmann and Steinmetz to P. & B.	$101/010/\bar{2}00$
Palache and Berman to L. & S.	$00\bar{1}/020/201$

One of the crystals studied by Palache and Berman was used for the x-ray investigation, which verified their choice of orientation and unit. Laubmann and Steinmetz chose a pseudo-orthorhombic cell which is directly comparable with the orthorhombic equivalent, hopeite. Peacock (1936) found in the case of roselite, as I do here, that it is incorrect to choose the lattice with the highest pseudo-symmetry if that lattice is multiple.

In phosphophyllite the planes (100) and ($\bar{1}$02) of Palache and Berman are planes of pseudosymmetry in the multiple pseudo-orthorhombic lattice of Laubmann and Steinmetz, but not in the simple lattice. According to the French school of twinning, these two planes should act as twin planes in the crystal. The following discussion of the twinning will show that this is the case.

Twinning on the plane (100) has been noted by all authors working on the mineral as being very common. In the Friedel sense this twin law would be a case of twinning by pseudoreticular merohedry with an index of 2 and an obliquity of 0°37′.

Kleber (1935) has described an additional twin law, which I have verified and identified on type material. The twin law is actually defined by the plane $\alpha\{\bar{1}02\}$; this is not in accord with Kleber. He states that the twin plane is normal to the c-axis, and that the twin axis is normal to $a(100)$. The twin plane $\alpha\{\bar{1}02\}$ is inclined 0°27′ to the plane normal to the c-axis. This results in a re-entrant of 0°54′ between the twinned (100) faces, which is the angle defined by Kleber.

The index of this twin is also 2, and the obliquity is 0°27′. Thus, we see that the two planes which are planes of pseudosymmetry in the multiple lattice do become the twin planes of the simple lattice.

Although the lattice of Laubmann and Steinmetz discloses the pseudosymmetry best, it is not the simplest lattice, and the indices of the forms referred to it, as has been shown by Palache and Berman, are more complex than when referred to the simple lattice.

The Relations of Phosphophyllite to Hopeite. The compositions of phosphophyllite and hopeite are quite similar, and some simple geometrical relations might be expected between them. Such is the case. The correlation of key forms is given below.

Phosphophyllite		Hopeite
100	=	020
010	=	001
001	=	110
$\bar{1}02$	=	200

The transformation formulae are:

(1) Phosphophyllite to Hopeite—001/201/010
(2) Hopeite to Phosphophyllite—$\frac{\bar{1}}{2}\frac{1}{2}0$/001/100

From the x-ray studies the angle between (100) and (001) is 59°45′. The correlative angle in hopeite, according to the above correlations, would be the angle between (010) and (110), which is 59°51′. This is excellent agreement. A further check on the correlation may be obtained by transforming the elements of one lattice according to the formula to obtain the elements of the other. If the transformed values are approximately the same as the values actually measured, the correlation is correct.

Transformation formula (1) above gives the following cell edges for hopeite as derived from the structural lattice of phosphophyllite:

$$a_0=10.49,\ b_0=17.68,\ c_0=5.08.$$

The values actually obtained for hopeite are:

$$a_0=10.64,\ b_0=18.32,\ c_0=5.03.$$

Likewise, from (2) we obtain the following cell edge lengths for phosphophyllite as derived from hopeite:

$$a_0=10.59,\ b_0=5.03,\ c_0=10.64.$$

The values actually obtained for phosphophyllite are:

$$a_0=10.23,\ b_0=5.08,\ c_0=10.49.$$

It is to be expected that the cleavages of the two minerals should also be closely related. That this is true is demonstrated below.

Cleavages in Phosphophyllite		Cleavages in Hopeite
{100}—perfect	=	{010}—perfect
{010}—distinct	=	{001}—poor
$\{\bar{1}02\}$—distinct	=	{100}—good

The angles between the three cleavages in phosphophyllite are practically 90 degrees within the limits of measurement, so they are directly comparable with the three pinacoidal cleavages of hopeite. The ease of cleavage, also, is practically the same for the equivalent faces in the two minerals.

A further relation between phosphophyllite, hopeite, and parahopeite appears in the indices of refraction. As was pointed out earlier, there is a definite relation of cell volume, density, and hardness to the symmetry in similar minerals. The higher the symmetry, the greater the cell volume per unit molecule becomes. With this increase in volume there is a corresponding decrease in density and hardness.

It has long been known that in most substances the mean refractive index is a partial function of the specific gravity. In substances whose chemistry is practically identical, this is especially true. Parahopeite, phosphophyllite, and hopeite are very similar chemically, and thus we may expect that the physical properties will vary directly with the symmetry. This is demonstrated in Table 9, where we see the indices of refraction, 2V, the specific gravity and the hardness increasing as the symmetry and cell volume decrease.

TABLE 9. RELATION OF PHYSICAL PROPERTIES TO SYMMETRY IN THE $A_3(XO_4)_2 \cdot 4H_2O$ FAMILY

Mineral	Symmetry	Volume per Unit Molecule	Sp. G.	Hardness	Indices	2V
Hopeite	Orth.	245.12	3.04	2.5–3	1.589 1.598 1.599	37°
Phosphophyllite	Mon.	235.46	3.14	3.5	1.595 1.614 1.616	54°
Parahopeite	Tri.	228.83	3.31	3.75	1.614 1.625 1.637	90°

Hopeite. The relations of hopeite to other members of the family have already been given. The principal problem in regard to hopeite is its symmetry.

Well-developed natural crystals of hopeite, $Zn_3(PO_4)_2 \cdot 4H_2O$, were first studied by Spencer (1908) on specimens from Broken Hill, S.W. Rhodesia. He figured several crystals which showed hemimorphic symmetry (Fig. 3, after Spencer), but stated that this hemimorphism was not a regular character and intimated that the phenomenon was fortuitous.

On other crystals from the same locality Ungemach (1910) noted that not only was the plane (010) of Spencer not a symmetry plane, as might be inferred from Spencer's figures, but that (001) of Spencer was, also, not a plane of symmetry. This led Ungemach to the conclusion that hopeite showed monoclinic symmetry. Further study, however, convinced him that the mineral was orthorhombic in all respects, save in its form development. He was, thus, led to postulate a "33rd crystal class," one which possessed but one plane of symmetry but was orthorhombic in all other respects. To differentiate this class of symmetry from the similar monoclinic classes, Ungemach chose a new setting in which the symmetry plane became horizontal. He went further in suggesting that a 34th symmetry class might similarly exist in the tetragonal system.

Three excellent specimens in the Harvard collection from S.W. Rhodesia were available for examination. With these I have corroborated the work of Spencer and Ungemach as to the appearance of the mineral, and demonstrated that hopeite is orthorhombic-dipyramidal, as concluded by Spencer, and does not represent a supposedly new symmetry type, as proposed by Ungemach.

In order to determine the symmetry, the crystals were studied morphologically, physically, and by x-ray methods. If Ungemach's analysis of the morphology were correct, disphenoidal symmetry is mandatory. The nature of the derivation of the 32 crystal classes excludes the 33rd which he postulated. Therefore, if hopeite were orthorhombic and if two of the normal symmetry planes were absent, the symmetry class would necessarily be disphenoidal, the third symmetry plane being only apparent or induced by twinning. That Ungemach's determinative crystals, however, must have been accidents of growth is shown below.

No new forms were noted on the several crystals measured. The purpose of the morphological investigation was to fix the symmetry, and to this end most of the crystals on the three specimens were studied, special attention being paid to form development and etching.

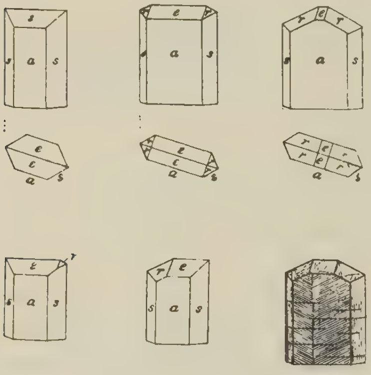

FIG. 3. Hopeite—after Spencer.

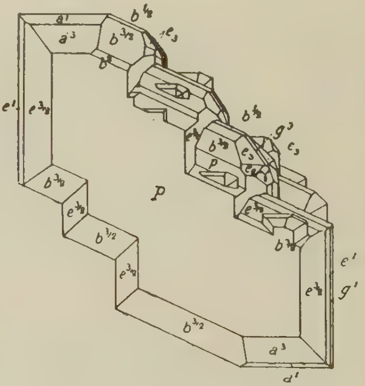

FIG. 4. Hopeite—after Ungemach.

The author is in agreement with Spencer that the symmetry evinced by the crystals is entirely irregular and fortuitous. On some the development is disphenoidal, on others, hemimorphic, and on still others, holohedral. Spencer (Fig. 3) shows the hemimorphic character of some as well as the holohedral character of others. Ungemach (Fig. 4, after Ungemach) depicts a crystal with but one plane of symmetry, but this is really the exception rather than the rule.

In Fig. 5, five crystals are shown which demonstrate the lack of uniformity in development. If any one crystal were used as a basis, the symmetry might be made triclinic-pedial, orthorhombic-pyramidal, orthorhombic-disphenoidal, or orthorhombic-dipyramidal. Such irregularity of growth must be due to the conditions existing at the time of crystallization and not to any lower symmetry of the crystals. Thus, on morphological grounds, alone, it seems that Spencer's decision for holohedry is correct.

Ungemach mentioned one of Spencer's figures (Fig. 3—bottom right) in which the markings of the crystal seem to indicate a twinning by merohedry. If this were truly twinning, a hemimorphic symmetry is indicated. Ungemach did not observe a similar phenomenon. Several of the crystals examined in this study, however, showed quadrilateral etch figures on the same plane ((010), new setting). Due to the stepped nature of this face, the etching was frequently interrupted, giving the impression of an irregular suture separating the two parts of the crystal. Wherever the etching occurred on a smooth, continuous surface, complete quadrilateral etch figures could be observed. The sutures were generally more irregular than that figured by Spencer, but it seems probable that both cases represent the same phenomenon and should not be ascribed to twinning.

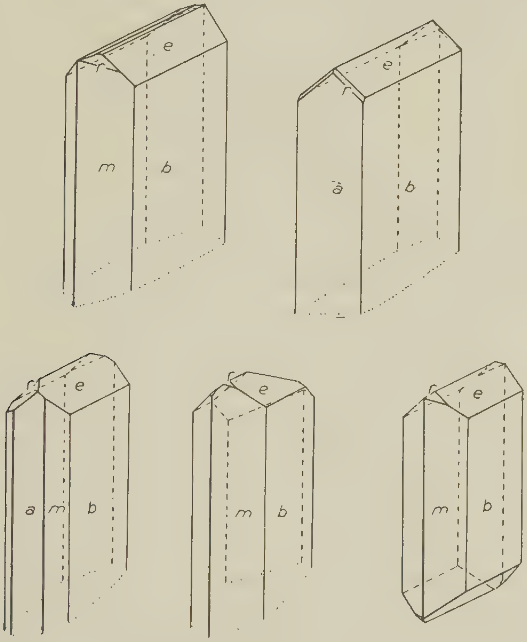

FIG. 5. Hopeite, Broken Hill, S.W. Rhodesia

Crystals which apparently possessed symmetry lower than holohedry, similar to or identical with those shown in Fig. 5, were tested for piezoelectrical properties with negative results. The instrument used was the same one which demonstrated so conclusively the piezoelectric nature of Hurlbut's (1938) parahilgardite. These tests were conducted in the Cruft Research Laboratory of Harvard University by Professor Pierce, who very graciously gave of his time and equipment for the experiment.

These tests, though not conclusive in themselves, add weight to the conclusion that hopeite is holohedral, the irregular development being a habit variation.

The *x*-ray study of hopeite included the taking of rotation, 0-layer-line, and 1-layer-line Weissenberg pictures about the [001] and about the [100] axes (new setting). From these the lengths of the cell edges were obtained: $a_0 = 10.64$, $b_0 = 18.32$, $c_0 = 5.03$ Å; yielding $a_0 : b_0 : c_0 = 0.5808 : 1 : 0.2745$; $M_0 = 1833.0 = 4\ Zn_3(PO_4)_2 \cdot 4H_2O$; theoretical specific gravity $= 3.08$.

The following spectral omissions were noted on the photographs:

(a) $0kl$ with $k+l$, even
(b) $hk0$ with h, even
(c) $h00$ with h, even
(d) $0k0$ with k, even
(e) $00l$ with l, even

(c), (d), and (e) are special cases of (a) and (b). Two space groups, only, are possible: $Pnma\text{–}D_{2h}^{16}$ or $Pna\text{–}C_{2v}^{9}$, the first being a space group of the dipyramidal, and the second of the pyramidal symmetry class. The first one is correct if (010), (100) of Spencer and (001) of Ungemach, is a plane of symmetry. This is the one plane of symmetry which Ungemach considered to be present, and, in Spencer's figures and in those of the author (Fig. 3), there can be little doubt that this is a symmetry plane in the majority of cases. Thus the space group is fixed as $Pnma\text{–}D_{2h}^{16}$, and the symmetry class automatically becomes orthorhombic-dipyramidal. This is conclusive evidence.

The axial ratio determined roentgenographically, $a_0 : b_0 : c_0 = 0.5808 : 1 : 0.2745$, is approximately equal to $b : 3a : c$ of Spencer. The interchange of a and b is necessitated by the requirements of the conventional orthorhombic setting in which b is greater than a. The transformation from Spencer's orientation to the structural orientation is: 010/300/001. Ungemach recognized the need of multiplying a by three, but, in order to make the one plane of symmetry horizontal, he interchanged a and c of Spencer or b and c of the structural lattice. The transformation from Ungemach's orientation to the one adopted in this paper is 010/001/100.

The relation of the transformed elements of Spencer and of Ungemach to those obtained by *x*-ray analysis is given below:

$b:3a:c$	Spencer	0.5761:1:0.2741
$b:c:a$	Ungemach	0.5754:1:0.2745
$a:b:c$	*x*-ray	0.5808:1:0.2745

The following optical properties were obtained, using matched liquids (measured on the minimum deviation goniometer):

$X=a$	1.589	Bx (−) negative
$Y=c$	1.598	2V=37°
$Z=b$	1.599	

These measurements were made on a single crystal which contained both the α and β varieties of hopeite as described by Spencer. The Weissenberg photographs showed no trace of inhomogeneity, however, and no successful attempt was made to separate the two. Although there seem to be two modifications of hopeite, none of the physical evidence obtained in this investigation demonstrates the existence of two species.

The 3.04 value for the specific gravity of hopeite obtained by Spencer using 1.035 grams of material in a pycnometer was duplicated in this study on a crystal weighing 0.012 grams.

Trichalcite—$Cu_3(AsO_4)_2 \cdot 5H_2O$?. Trichalcite occurs in thin pseudohexagonal plates. Data concerning the mineral are very scarce, there being very little recorded on the crystallography and no specific gravity. The one analysis by R. Hermann (1858) on material from Turginsk in the Urals shows considerable divergence from the theoretical composition of the above formula.

Some of the Turginsk material was kindly supplied for this study by W. F. Foshag from the U. S. National Museum collection.

The mineral was easily recognized but showed little promise for fruitful research. There was not sufficient material to obtain a specific gravity. The optical properties checked those given in the literature.

Inasmuch as the composition is not certain, it seemed advisable to make a Weissenberg study to gain some idea as to the probability of the assigned formula. The orientation of a plate for study proved difficult, but after two attempts a crystal gave satisfactory results, which are listed in Table 10. It was impossible to determine the space group with the data obtainable. Rotation, 0-layer-line, and 1-layer-line pictures with [100] as the axis of rotation were used in the calculations. The value for b_0 may be 1 per cent in error.

It would be better perhaps to orient b_0 as the c-axis, since this is the pseudohexagonal axis of the morphology and was made c by Shannon (1922), who observed the three forms $c\{001\}$, $b\{010\}$, and $m\{110\}$. If the convention of $b>a>c$ be followed, the forms of Shannon must be transformed by the formula 010/001/100, making them:

Shannon	Wolfe
$c(001)$	$b(010)$
$b(010)$	$a(100)$
$m(110)$	$d(101)$

The ever-present twinning on the old *m*(110) will, in the new orientation, be defined by the twin plane *d*(101). Shannon noted that his prism angle was about 60 degrees. Using the *x*-ray values, the equivalent angle in the new orientation, (101) to (100), is 61°41½′.

Table 10. Data on Trichalcite

$a_0 = 10.34$
$b_0 = 26.9$ $a_0:b_0:c_0 = 0.384:1:0.207$
$c_0 = 5.57$
$V_0 = 1549.3$ Å

The cell volume is 1549.3 Å^3. The orthorhombic minerals of the chemical type have four molecules to the unit cell. If we suppose that this is true for trichalcite, the volume per unit molecule would be 387.3 Å^3. Turning to Table 1, we see that the average volume per unit molecule in the $8H_2O$ family is only about 309Å^3. Thus, trichalcite, with only $5H_2O$, should have a smaller volume, if it is to harmonize with the theory of this classification. As it is actually larger, it seems reasonable to assume that the formula given is incorrect and that it probably does not belong to the type. Further study must await a new analysis.

The $A_3(XO_4)_2\cdot 8H_2O$ Family

This family of minerals under the name of the *vivianite group* has long been recognized as being interrelated. Most of the relations are well established, and for many of the species within the family, no additional data are required. Barth (1937) has completed the *x*-ray work on vivianite, bobierrite, erythrite, and annabergite. He has also summarized most of the pertinent data relative to the entire family.

It has been necessary, then, for the purposes of this classification, to examine only those minerals of the family which he has not treated. These include symplesite, köttigite, and hörnesite. All of the data concerning the other minerals which are given in Table 11, except for Barth's *x*-ray data, have been checked.

This family has long been considered to represent an isomorphous series. The discovery made during the course of this research that symplesite is triclinic requires, however, that the family be considered iso-dimorphous with triclinic and monoclinic groups.

Choice of Unit Cell. Barth has shown that the morphological elements of the family which are commonly given do not represent what he considers the true unit cell, but this supposed unit of Barth is not in the generally accepted orientation because it is body-centered. He has suggested that the morphological elements be retained, as there is an increase in complexity of indices when the known forms are referred to his so-called true cell. In giving his x-ray elements, therefore, he has retained the orientation of morphology while giving the correct cell edge lengths in that position.

Actually, this orientation is the one that would be chosen conventionally, as it produces a face-centered lattice. It seems wise, then, to retain this orientation, and it also seems wise to describe the morphology in terms of the true lattice rather than in terms of the traditional morphological lattice. The reason for this last statement is as follows. The form indices referred to the traditional morphological unit do not reflect the fact that the basic lattice is a centered one. Donnay (1937 and other references) has convincingly suggested that the elements chosen to describe a mineral should actually portray not only the crystal class but also the space group. This is logical and especially sound in formulating a satisfactory classification.

Inasmuch as no great complexity is introduced when the forms are referred to the base-centered cell and inasmuch as such a reference gives form indices which are compatible with the centered lattice, I believe that it would be better to use the base-centered cell for descriptive purposes in the future. The transformation, morphological lattice to base-centered lattice, is:

$$100/010/00\tfrac{1}{2}$$

Optical Properties. It is to be expected that members of this family will show similar optical properties with variation compatible with the change in cation and anion content. That this is clearly so is shown in Table 11, the data for which have been obtained, after checking, from the tabulations of Ulrich (1926), Larsen and Berman (1934), and Barth (1937). The optics of köttigite as given in Table 11 are new and will be discussed under that mineral.

Chemistry. The minerals of the family are arsenates or phosphates with 8 molecules of water of hydration and with Fe, Ni, Co, Zn, or Mg acting as cations. Theoretically, a considerable amount of isomorphous replacement is possible, as these ions have similar radii. Actually, but little has been noted. This lack is probably due in part to the paucity of analyses that have been made. At present the various minerals of the family represent almost pure members, there being but one cation listed in the formula of each.

Symplesite-$Fe_3(AsO_4)_2 \cdot 8H_2O$. The crystallography of this mineral has been treated by Krenner (1886). He chose a lattice and cell which were monoclinic and directly comparable with the other members of the family. The x-ray investigation carried out in conjunction with this work, however, demonstrates that the lattice is not monoclinic as supposed by Krenner, but is triclinic.

TABLE 11. DATA OF THE $A_3(XO_4)_2 \cdot 8H_2O$ FAMILY

Mineral	Symplesite	Vivianite	Annabergite	Erythrite	Köttigite	Bobierrite	Hoernesite
Composition	$Fe_3(AsO_4)_2 \cdot 8H_2O$	$Fe_3(PO_4)_2 \cdot 8H_2O$	$Ni_3(AsO_4)_2 \cdot 8H_2O$	$Co_3(AsO_4)_2 \cdot 8H_2O$	$Zn_3(AsO_4)_2 \cdot 8H_2O$	$Mg_3(PO_4)_2 \cdot 8H_2O$	$Mg_3(AsO_4)_2 \cdot 8H_2O$
Crystal	Triclinic	Monoclinic	Monoclinic	Monoclinic	Monoclinic	Monoclinic	Monoclinic
Crystal Class	Pinacoidal	Prismatic	Prismatic	Prismatic	Prismatic	Prismatic	Prismatic
Space group	$C_i^1-P\bar{1}$	C_{2h}^3-C2/m	C_{2h}^3-C2/m	C_{2h}^3-C2/m	C_{2h}^3-C2/m	$C_{2h}^5-P2_1/c$	?
a_0	7.85	10.039	10.122	10.184	10.11	9.946	
b_0	9.39	13.388	13.284	13.340	13.31	27.654	
c_0	4.71	4.687	4.698	4.73	4.70	4.639	
$a_0 : b_0 : c_0$	0.8320:1:0.5027	0.7499:1:0.3501	0.7619:1:0.3537	0.7633:1:0.3546	0.7593:1:0.3531	0.3596:1:0.1668	
α	99°55′						
β	97°22½′	104°18′	104°45′	105°02′	103°50′	104°01′	
γ	105°57½′						
Morphology $a:b:c$	Unsatisfactory	0.7498:1:0.7017	0.7874:1:0.7223	0.7648:1:0.7122			0.7676:1:0.7182
Cell Volume	321.82	610.43	609.84	620.65	613.95	1238.0	
Cell Contents	1 molecule	2 molecules	2 molecules	2 molecules	2 molecules	4 molecules	
Sp. G. Meas.	3.012	2.676	3.07	3.09	3.33		2.73
Sp. G. Calc.	3.022	2.711	3.235	3.182	3.32	2.17	
Cleavages	$(1\bar{1}0)$	(010)	(010)	(010)	(010)	(010)	
Hardness	2.5	1.5–2	2	1.5–2.5	2.5–3		
Optical Sign	−	+	−	+ or −	+	+	+
2V	87°	83°	84°	90°	74°	71°	60°
$r:v$	$r>v$ strong	$r<v$ weak	$r>v$ strong	weak	imperceptible	$r<v$ weak	
Indices of Refraction	1.635 1.668 1.702	1.579 1.603 1.633	1.622 1.658 1.687	1.626 1.661 1.699	1.622 1.638 1.671	1.510 1.520 1.543	1.563 1.571 1.596
X	⊥ to (110)	b	b	b	b		b
Y						b	
Z		to $c=28°$	to $c=30°$	to $c=31°$	to $c=37°$	to $c=30°$	to $c=31°$
Locality	Voigtland	Monserrat	Laurion	Schneeberg	Schneeberg	Mexillones	Joachimstal

Rotation, 0-layer-line, and 1-layer-line pictures were taken about the long axis of a single fibrous crystal selected from a radiating aggregate. Reciprocal lattice projections of the 0-layer-line and of the 1-layer-line pictures showed interpenetrating lattices similar to those already described for roselite, the twin plane being equivalent to the symmetry plane of the monoclinic members. As a twin plane cannot be a symmetry plane, it was necessary to conclude that the mineral was triclinic or that the crystal was peculiarly distorted. To make sure that the latter was not the case, an entirely new and complete Weissenberg study was made on another fiber. Identical results were obtained. Thus, it must be concluded that symplesite is triclinic. The relations between the monoclinic cell and the triclinic cell are rather complex, as the old $a\{100\}$ plane becomes (230) in the triclinic orientation. The transformation is: monoclinic to triclinic—

$$\tfrac{2}{5}\tfrac{1}{2}0/\tfrac{2}{5}\tfrac{\bar{1}}{2}0/001$$

The elements of Krenner may be transformed to those of the triclinic cell by the formula:

$$\tfrac{2}{5}\tfrac{1}{2}0/\tfrac{2}{5}\tfrac{\bar{1}}{2}0/00\tfrac{1}{2}$$

These elements: $a:b:c=0.7806:1:0.6812$, $\beta=107°17'$, transformed according to the preceding formula, give the following values for the triclinic cell edges as compared with those obtained by x-ray study:

$$a:b:c=0.8604:1:0.4972$$
$$a_0:b_0:c_0=0.8320:1:0.5027$$

There is a decided discrepancy between the values for a obtained by the two methods, but, as the crystals of symplesite are never very suitable for measurement, the x-ray values are probably better.

As has already been noted, twinning was first observed on the reciprocal lattice projections of the x-ray pictures. An attempt was made to substantiate the x-ray evidence by optical observations. When the flat cleavage face $\{1\bar{1}0\}$ [(010) of the monoclinic setting] which is the twin plane, is vertical, twinning is most easily detected. After much manipulation, a few fibers were set in that position and examined. No definite confirmation of the twinning could be found. The extinction of the fibers in this position, however, was never complete, which may or may not be significant. Perhaps better crystals of symplesite will be found, enabling a check to be made on the conclusions drawn from the x-ray analysis.

The measured (3.012) and calculated (3.022) specific gravities are in close agreement, checking the results of the x-ray study.

Vivianite. Vivianite has been thoroughly studied, and only the specific gravity has been determined here. Specimens of the mineral from Leadville, Victoria, and Llallagua were studied and gave 2.687, 2.668, and

2.674 respectively, with an average of 2.676. This is somewhat lower than 2.711, the calculated value obtained by Barth (1937) on material from Monserrat, but, as the three localities gave values close to the average, it seems probable that this average represents the best value for the mineral. The best data concerning the mineral are summarized in Table 11.

Annabergite. Barth (1937) has given the essential facts concerning annabergite, and they are included in Table 11. His calculated value for the specific gravity of material from Laurion, 3.235, is much higher than the measured specific gravity 3.07, which I obtained on material from the same locality. This is no doubt due to the poor material with which he was working, since there was but very poor agreement between the x-ray and morphological axial ratios. Barth (1937) discarded the species cabrerite, which was presumably a magnesium-bearing annabergite, on optical grounds. According to Barth (and logically enough) the indices of refraction of such a mixed mineral should be considerably lower than those of the pure nickel member. As they actually were not, in spite of analyses showing from 6 to 9 per cent of magnesium oxide, Barth concluded that there actually was little or no magnesium present and that there was no need to retain the species. It might be pointed out, however, that the presence of a small amount of magnesium would materially lower the specific gravity—enough, in fact, to explain the wide discrepancy in calculated and measured specific gravities. A reliable new analysis of so-called cabrerite is needed. In spite of Barth's decision to discard the name, it seems best here to retain it as a varietal modifier of annabergite, with the composition $(Ni,Mg)_3(AsO_4)_2 \cdot 8H_2O$.

Erythrite. Barth's x-ray measurements of erythrite give what are probably the best elements, as crystals thus far observed are too poor to permit accurate measurement. No new research, except for an accurate determination of the specific gravity, has been done here.

Since Barth worked on erythrite from Schneeberg, the specific gravity was determined on material from the same locality. Once more, a wide discrepancy between measured (3.09) and calculated (3.182) values exist, the reason for which is not apparent.

Köttigite. The crystallography of this mineral has never been adequately described. Material for investigation from Schneeberg was kindly loaned by Dr. F. Pough of the American Museum of Natural History. Although crystals are common, most of them are so etched and rounded that a goniometric treatment of them is impossible. One section of the specimen, however, carried a few unetched crystals with a habit like that of annabergite.

A blowpipe test for zinc was positive, indicating the probability that the mineral was köttigite. Optical tests demonstrated that the mineral could not be erythrite, which resembles it in color. On the other hand, the values for the indices of refraction determined for the mineral were in complete disagreement with those listed by Larsen and Berman for köttigite. Inasmuch as the zinc test was positive and since the newly determined optical properties are in agreement with properties of a zinc member of this family, as inferred from other families of this chemical type, it seems probable that the identification of the mineral as köttigite is correct and that the data derived from it are authentic for the species.

Five crystals were measured on the optical goniometer, the average size of which was 0.5 mm. in largest dimension. The orientation of the crystals was difficult, due to the poor reflections from most of the faces. The same five forms were noted on all of the crystals. These were $b\{010\}$, $a\{100\}$, $m\{110\}$, $n\{201\}$, and $v\{\bar{2}21\}$. All except $n\{201\}$ gave consistent angular readings. This face, however, varied considerably in its position, the ρ angle varying between 40° and 50° approximately, while the calculated angle was $50°38\frac{1}{2}'$. The variation is due to the considerable amount of etching on the face. As its position most nearly approximates the position of (201) and as such indices conform to the probabilities of form occurrence suggested by the space group and also because the form is a very prominent one, it seems permissible and probably correct to give it the indices suggested above. All of the form indices in Table 12 are derived with reference to the simple, base-centered lattice.

TABLE 12. KÖTTIGITE: ANGLE TABLE

Monoclinic—Prismatic

$a_0:b_0:c_0 = 0.7593:1:0.3531$; $\beta = 104°30'$; $p_0:q_0:r_0 = 0.4650:0.3419:1$

$r_2:p_2:q_2 = 2.9253:1.3603:1$; $\mu = 75°30'$; $p'_0 = 0.4803$, $q'_0 = 0.3531$, $x' = 0.2586$

Forms	ϕ	ρ	ϕ_2	ρ_2	C	A
b 010	0°00′	90°00′	—	0°00′	90°00′	90°00′
a 100	90 00	90 00	0°00′	90 00	75 30	—
m 110	53 41	90 00	0 00	53 41	78 21½	36 19
n 201	90 00	50 38½	39 21½	90 00	36 08½	39 38½
v $\bar{2}21$	−44 49½	44 52½	54 56	59 58½	55 50½	60 10

Figure 6 shows the typical habit of köttigite from Schneeberg.

Rotation, 0-layer-line, and 1-layer-line pictures were taken with $c[001]$ as the axis of rotation. The rotation and 0-layer-line pictures taken about $b[010]$ were rather unsatisfactory. The determination of β as listed in Table 11 may be as much as 20 minutes in error, as neither the morphological nor the x-ray studies permitted an accurate determination. The cell constants derived from these pictures are given in Table 11 and are very similar to those of annabergite and erythrite, as is to be expected.

The optical properties listed for köttigite in Table 11 are different from those formerly given for the species. They were measured with sodium light.

The measured specific gravity (3.33) in Table 11 compares favorably with the calculated one (3.32). The hardness conforms to earlier descriptions.

Bobierrite. No specimens of bobierrite suitable for study are available at Harvard, but Barth has already made an x-ray study of the mineral and has shown its relations to the other members of the family. Previously De Schulten (1903) obtained a specific gravity of 2.195 on artificial material, and Lacroix obtained 2.41 on natural material. The calculated value obtained by Barth was 2.169. It is desirable that a trustworthy determination for the natural material be made in order that a significant comparison between the calculated and measured values may be made.

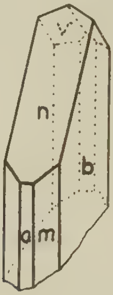

Fig. 6. Köttigite from Schneeberg.

It will be noted that bobierrite, though directly related geometrically and chemically to the $8H_2O$ family, belongs to a different space group from that of the other monoclinic members. In fact, the space group here is the same as that of roselite, brandtite, and phosphophyllite, members of the $2H_2O$ and $4H_2O$ families. The meaning of this is not clear. Strunz and Schroeter (1939) have questioned the place of bobierrite with the rest of the vivianite family because of the different space group. That it might well represent another group in the $8H_2O$ family is possible, but it is certainly a member of the family. Without work on better material, it is impossible to be more specific concerning its place in the classification.

Hoernesite. This mineral, the arsenate analogue of bobierrite, has been described crystallographically by Zambonini (1919). The material used was rather unsatisfactory. No other contributions have since been made. Three attempts were made to carry out a Weissenberg study on some very fine fibers of hoernesite from Joachimstal, but the crystals proved too small to give satisfactory diffraction patterns.

The rotation picture gave a value of 6.61 for the translation period of the axis of rotation. This is just half of the value obtained for b_0 on vivianite, annabergite, erythrite and köttigite. The picture is faint, and it is possible that a halving might have escaped detection. The 0-layer-line picture, after 32 kilowatt hours of exposure, showed but 11 reflections, none of which was good. From these, two poor determinations for spacings, 3.14 Å and 3.8 Å, were obtained. If these are considered to be some multiple of the spacings of $a(100)$ and $c(001)$ and if μ be taken to be about 75° (as it is in the other members of the family), some submultiple of the cell volume is obtained by proper multiplication. This volume proves to be 81.6 Å, which, if multiplied by four, is very similar to the average value for the family. The calculated specific gravity for such a volume is 2.82, which is much higher than any listed values for the mineral. I obtained 2.73 on the Joachimstal material. No further refinement is possible with the material at hand. Actually, the measurements probably mean little.

There is no doubt that hoernesite belongs to the $8H_2O$ family, but the question remains unanswered as to whether its space group conforms to that of bobierrite or to that of the other monoclinic members of the family.

CONCLUSION

The preceding discussion has demonstrated the important part that water of crystallization plays in determining the properties of related minerals. Within any chemical type, where the cation and anion content varies only within prescribed limits, the number of water molecules present in the simplest formula is the controlling factor in the determination of the properties of the minerals and, consequently, of the position of the minerals in the classification.

As the result of this investigation, we may conclude that hydrated minerals should be classified together with their anhydrous analogues in the same type and that the properties of the minerals of any one type will vary in some simple way with the water content in the directions indicated in this paper.

Thus, if we assume the general formula of a type to be $AX \cdot nH_2O$ (where A is the entire cation content and X is the entire anion content), the type will be classified into families on the basis of the change of n in the simplest formula. In the general type formula, n may vary between 0 and an indefinite number.

The anhydrous minerals of the type will be classified as a single family, and all hydrates with different water compositions will be placed in separate families. A more detailed chemical subdivision will often be possible within the types, but, in general, the above method of classification seems sound.

It should be noted that the classification of the hydrated phosphates, arsenates, and vanadates with their anhydrous analogues is a new departure and is counter to the recent classification of Strunz and Schroeter (1939) and earlier classifications, which divide them into water-free and water-containing sections.

The present paper is not the place for a complete classification of these compounds, but such a classification, when made, should be developed along these lines. It is only necessary here that the $A_3(XO_4)_2 \cdot nH_2O$ type be placed in its proper relation to other types containing the (XO_4) radicle as a matter of orientation in the general classification.

Three important chemical types in this category follow.

(1) $A''B'\ (XO_4)''\cdot nH_2O$
(2) $A_3''\ (XO_4)''\cdot nH_2O$
(3) $A''\ (XO_4)''\cdot nH_2O$

Type (1) includes such anhydrous minerals as the triphylite group and such hydrous minerals as dickinsonite and fillowite. Type (2) has been discussed in this paper. In type (3) we find, in the anhydrous family, monazite, xenotine, and pucherite, and, in the hydrated families, the variscite group, koninckite, and others. *X*-ray diffraction and other evidence indicate that these types are notably different.

Acknowledgments

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DECOMPOSITION AND ALTERATION OF FELDSPARS AND SPODUMENE BY WATER

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ABSTRACT

In an attempt to effect considerable decomposition and to produce one of the clay minerals, samples of microcline, albite, and kunzite were reduced to particles less than 0.1 micron in diameter by grinding them for 394 hours and more under water in an agate mortar and pestle. The suspensions produced were electrodialyzed in the mortar, and it was found that all of the constituents of these minerals diffused through the membrane of the dialyzer. This was interpreted as evidence that silica and alumina, as well as the alkalis, were present in solution as ions, indicating that clay minerals may probably form, at least in part, by ionic reactions rather than by colloidal reactions. Over 50 per cent of the alkalis were removed from the feldspars by dialysis; the kunzite lost 44 per cent of its lithia. The decomposed minerals were hydrated. About 50 per cent of the water could not be expelled at 100°C., and some of it still remained at 500°C. Dehydration data suggested that the water was merely adsorbed on the mineral particles. *X*-ray photographs showed that substantial amounts of the minerals were undecomposed and that no detectable new mineral had been formed. After treatment of the decomposed materials in water in a bomb at 300°C., *x*-ray evidence for the formation of quartz and perhaps of kaolinite was found. The particles of the original minerals may also have increased in size during the hydrothermal treatment.

INTRODUCTION

Since several investigators in geology and in soil science have demonstrated that feldspars can be partially decomposed in the laboratory by cold water, this investigation was undertaken for the purpose of determining the amount of decomposition which could be effected by prolonged grinding of feldspars in water. Another purpose was to determine by the powder method of *x*-ray analysis if one of the clay minerals could be produced, either by this method at temperatures normally found in weathering, or by treatment of the material after grinding with water at elevated temperatures.

The counsel of Professor John W. Gruner in connection with the execution of the experimental work and with the preparation of this paper is gratefully acknowledged. The writer is also indebted to Dr. R. B. Ellestad for assistance with the analytical work and for helpful suggestions.

This study was made possible by the aid of the Graduate School of the University of Minnesota. The work was completed in December 1937, but due to unforeseen circumstances, it could not be published until now.

WORK OF OTHER INVESTIGATORS

As early as 1848, W. B. and R. E. Rogers[1] found that finely powdered feldspars gave an alkaline reaction when moistened with water. Similar experiments on the alkalinity of feldspars were conducted by Kenngott,[2] Clarke,[3] Tamm,[4] and Stevens.[5] Stevens showed that feldspars, spodumene, and numerous other silicates released enough bases when ground in carbon dioxide-free water to give a basic *pH*. Tamm also demonstrated that finely pulverized feldspars have a basic *pH* in water and that they adsorb water, a portion of which can not be eliminated by heating at 110°C. More recently, the work of Correns and v. Engelhardt[6] has indicated that all components of a feldspar go into true ionic solution. After treatment of adularia in water and in weak acid solutions, they found that even silica and alumina diffused through the membrane of an ultrafiltration apparatus.

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[1] Rogers, W. B., and R. E., Decomposition and partial solution of minerals: *Am. Jour. Sci.*, 2d ser., **5**, 401–405 (1848).

Except for the experiments of Collins,[7] in which hydrofluoric acid was used, the production of clay minerals by the alteration of feldspars in cold solutions has not been reported in the literature. At elevated temperatures, however, some of the clay minerals have been formed in the laboratory by two methods. First, Badger and Ally,[8] Schwarz and Trageser,[9,10] and Norton[11,12] have altered feldspars with hot carbonated water and weak acid solutions; and secondly, Noll,[13,14,15] Ewell and Insley,[16] and Gruner,[17] using co-precipitated silica-alumina gels and mixtures of silica and alumina in various solutions, have synthesized kaolinite and other hydrous compounds of silica and alumina.

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[2] Kenngott, A., Über die alkalische Reaction einiger Minerale: *Neues Jahrb.*, 778–779 (**1867**).

[3] Clarke, F. W., Alkaline reaction of some natural silicates: *U. S. Geol. Survey, Bull.* **167,** 156 (1900).

[4] Tamm, O., Experimentelle Studien über die Verwitterung und Tonbildung von Feldspaten: *Chemie der Erde*, **4,** 420–430 (1930).

[5] Stevens, R. E., Studies of the alkalinity of some silicate minerals: *U. S. Geol. Survey, Prof. Paper* **185-A,** 1–13 (1934).

[6] Correns, Carl W., and v. Engelhardt, Wolf, Neue Untersuchungen über die Verwitterung des Kalifeldspats: *Chemie der Erde*, **12,** 1–22 (1938).

[7] Collins, J. H., On the nature and origin of clays: *Min. Mag.*, **7,** 205–214 (1886).

[8] Badger, A. E., and Ally, A., Note on the formation of kaolin minerals from feldspars: *Jour. Geology*, **40,** 745–747 (1932).

[9] Schwarz, R., and Trageser, G., Über die kunstliche Umwandlung von Feldspat in Kaolin: *Zeit. anorg. Chemie*, **215,** 190–200 (1933).

[10] ———, Kunstliche Umwandlung von Feldspaten in Pyrophyllit: *Naturwiss.*, **23,** 512 (1935).

[11] Norton, F. H., Accelerated weathering of feldspars: *Am. Mineral.*, **22,** 1–14 (1937).

[12] ———, Hydrothermal formation of clay minerals in the laboratory: *Am. Mineral.*, **24,** 1–17 (1939).

[13] Noll, W., Hydrothermale Synthese des Kaolins: *Min. pet. Mitt.*, **45,** 175–190 (1934).

[14] ———, Mineralbildung im System $Al_2O_3-SiO_2-H_2O$: *Neues Jahrb.*, **70,** 65–115 (1935).

[15] ———, Über die Bildungsbedingungen von Kaolin, Montmorillonit, Sericit, Pyrophyllit, und Analcim: *Min. pet. Mitt.*, **48,** 210–247 (1936).

[16] Ewell, R. H., and Insley, H., Hydrothermal synthesis of kaolinite, dickite, beidellite, and nontronite: *Jour. Research U. S. Bur. Standards*, **15,** 173–186 (1935).

Experimental Work

Apparatus Employed

A machine, consisting essentially of a mechanically rotated agate mortar and pestle, was used for grinding the minerals in distilled water. It was belted to a motor-driven reduction gear in such manner that the pestle revolved about 80 r.p.m. in a clockwise direction while the mortar turned one r.p.m. in the opposite direction.

As the grinding produced suspensions too fine-grained to filter by ordinary methods, an electrodialyzer was used for this process. To eliminate repeated transferences of suspensions from one container to another and to permit the pestle to act as a stirrer, the dialyzer was attached to the grinding machine and designed so that the mortar with its suspension served as the anode compartment. The cathode compartment, consisting of a pyrex glass tube sealed off at one end by a cellophane membrane dipping into the suspension, was continually rinsed by small amounts of distilled water. The electrodes were of platinum. They were connected to a source of 220 volts D.C., and the distance between them was varied to prevent heating of the solutions. Grinding and dialysis were continued until a tiny drop of phenolphthalein introduced into the cathode liquid indicated that bases were no longer being removed from the suspension.

Dehydration of samples of air-dried mineral residues, remaining in the mortar after grinding and dialysis, was carried out in a vacuum apparatus designed very similar to the "tensi-eudiometer" described and successfully used by Calsow[18] in the identification of kaolinite by the shape of its dehydration curve. The portion of the apparatus containing the sample was heated in a small electric furnace maintained to within 3°C. of the desired temperature by a Leed-Northrup thermostatic control.

Small samples of the air-dried residues were treated hydrothermally in a gold-lined, steel bomb with a capacity of 50 cc. The bomb charge consisted only of 20 cc. of distilled water and a half gram of residue; it was maintained at 300°C. in a thermostatically controlled electric furnace.

X-ray powder photographs of the minerals used in the experiments, the residues, and of the hydrothermally treated residues were obtained. All exposures were made in a circular camera with a radius of 57.3 mm. using unfiltered Fe radiation.

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[17] Gruner, J. W., Formation and stability of muscovite in acid solution at elevated termperatures: *Am. Mineral.*, **24**, 524–528 (1939).

[18] Calsow, G., Über das Verhaltnis zwischen Kaolinen und Tonen: *Chemie der Erde*, **2**, 415–441 (1926).

Minerals Used

Two feldspars, microcline and albite, were used in the experiments, and kunzite, a variety of spodumene, was also employed. The compositions of the fresh minerals and of the residues left in the agate mortar after grinding and dialysis are given in Table 1. All analyses were made in the Rock Analysis Laboratory, Department of Geology, University of Minnesota. The methods used were essentially the same as those set forth by Hillebrand and Lundell.[19] Lithium was determined by the procedure described by Wells and Stevens.[20]

TABLE 1. ANALYSES OF MINERALS USED AND OF RESIDUES
(L. C. Armstrong, analyst)

	Microcline		*Albite*		*Kunzite*	
	Fresh	Residue	Fresh	Residue	Fresh	Residue
	%	%	%	%	%	%
SiO_2	65.46	74.35	66.01	69.98	64.20	61.05
Al_2O_3	19.12	8.53	21.40	11.87	28.02	19.37
CaO	nil	nil	1.74	.37	nil	nil
Na_2O	3.51	.64	10.27	2.73	.18	.04
K_2O	11.93	2.26	.56	.23	.05	.04
Li_2O	n.d.	n.d.	n.d.	n.d.	7.62	2.92
Ignition	0.18	14.20	.27	14.76	.05	16.52
Total	100.20	99.98	100.25	99.94	100.12	99.94

Microcline: Locality unknown. Grayish white cleavage fragments. Albite present in perthitic intergrowth; calculation of the norm indicates a composition of 70.6 per cent orthoclase and 29.4 per cent albite.

Albite: Locality unknown. Grayish white moonstone cleavage fragments; calculation of the norm indicates a composition of 86.8 per cent albite, 8.6 per cent anorthite, and 3.1 per cent orthoclase.

Kunzite: From San Diego County, California. Transparent lilac-tinted cleavage fragments.

Decomposition and Hydration Effects

The data relative to grinding and to the amount of material which diffused through the cellophane membrane to the cathode are listed in Table 2. As described in the foregoing, the cathode compartment of the electrodialyzer was continually rinsed by small amounts of distilled water. These cathode solutions, which were clear and free from sediment, were evaporated to dryness in platinum dishes, and the residues were analyzed to determine the number of milligrams of each substance removed in solution. From these weights, the m.e. (milliequivalents—equivalent weights in milligrams) have been calculated to show the relative number of ions of bases removed from each of the three minerals.

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[19] Hillebrand, W. F., and Lundell, G. E., *Applied Inorganic Analysis*, John Wiley and Sons, New York, **1929.**

[20] Wells, R. C., and Stevens, R. E., Determination of the common and rare alkalis in mineral analysis: *Ind. and Eng. Chem.*, **6,** 440 (1934).

Table 2. Data on Grinding and Electrodialysis

	Microcline	*Albite*	*Kunzite*
Wt. of sample (gms.)	3	4	4
Time ground (hrs.)	921	876	394
Volume of cathode solution (cc.)	2000	2000	1500

Amount of Material in the Cathode Solution

	From Microcline		*From Albite*		*From Kunzite*	
	mgms.	*m.e.*	*mgms.*	*m.e.*	*mgms.*	*m.e.*
SiO_2	16.4		73.5		24.8	
Al	6.4	.71	3.7	.41	5.0	.55
Ca	nil		21.7	1.08	nil	
Na	49.6	2.15	160.2	6.96	n.d.	
K	156.1	3.99	9.6	.24	n.d.	
Li	n.d.		n.d.		59.0	8.50
Total	228.5	6.85	268.7	8.69	88.8	9.05

Calculated on the basis of a four-gram sample, the m.e. of bases removed in solution from the microcline would be 9.13 instead of 6.85 as given in Table 2. It is interesting to note that this figure agrees closely with the m.e. of bases removed from four gram samples of albite and kunzite, indicating that each gram of the three minerals lost about the same number of positively charged ions during the artificial weathering process. However, these data are not strictly comparable. The kunzite was not ground as long as the feldspars, and *x*-ray investigations showed that it was probably the coarsest grained of the three minerals.

As in natural weathering, alumina and silica were the most difficultly soluble. The albite lost considerably more silica than did the other two minerals. This was verified by grinding additional samples of albite and microcline and dialyzing with the current reversed, so that the mineral suspension was in the cathode compartment and the anode was in distilled water. After grinding each sample for 100 hours, the anode solution from albite contained over 50 per cent more silica than that from microcline. Only small traces of alkalis were found in the anode solutions, which excludes the possibility that silica diffused through the membrane as alkali silicate molecules. In an identical experiment conducted with two grams of transparent colorless quartz, the anode solution contained 6.6 milligrams of silica. It seems very probable that some of the silica from the finely ground feldspars and quartz was hydrolyzed to silicic acid and migrated to the anode as negatively charged silicate ions. The presence of silica in the cathode diffusates (Table 2) is more difficult to explain; it may have entered the cathode compartment of the dialyzer as alkali silicate molecules. The bases (Na, K, Ca, Li, and Al) undoubtedly diffused to the cathode as positively charged ions. These data, then, support the observation of Correns and v. Engelhardt[21] that all components of a feldspar go into true ionic solution. This, as they point out, throws new light on the weathering of silicates and the formation of hydrous silicates. It is probable that clay minerals may form, at least in part, by ionic reactions rather than by colloidal reactions as it has been generally believed.

The analyses of the minerals used and those of their respective residues remaining in the mortar after grinding and dialysis are compared in Table 1. The analyses have been recalculated to total 100 per cent in Table 3, and the losses and gains in each constituent have been computed on the assumption of no change in the alumina content. Actually, some alumina was lost by each mineral (see Table 2), but these losses were so small that they do not seriously affect the accuracy of the calculated changes.

Due to wear of the agate mortar and pestle, large amounts of silica were introduced. The microcline, for example, gained 101 per cent of silica by weight from the mortar and pestle. It also gained 31 per cent of water by weight. Since the albite and kunzite did not gain as much silica or as much water as the microcline (Table 3, column D), it seems probable that a part of the water held by the residues may be due to hydration of the silica added from the mortar and pestle.

The microcline lost 59 per cent of its soda and 57 per cent of its potash (Table 3, column F). A greater percentage of soda than of potash was also dissolved from the albite, and the percentage of lime dissolved was larger still. Therefore, if it is assumed that a major portion of the silica removed by dialysis came from the minerals rather than from the agate worn from the mortar and pestle, the rate of solution of the components of the feldspars may be given as follows: $CaO > Na_2O > K_2O > SiO_2$

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[21] Correns and v. Engelhardt, *op. cit.*

TABLE 3. CALCULATION OF LOSSES AND GAINS

	Microcline					
	A	B	C	D	E	F
	%	%	%	%	%	%
SiO_2	65.33	74.37	166.35	+101.02	—	+154.63
Al_2O_3	19.08	8.53	19.08	—	—	—
Na_2O	3.50	.64	1.43	—	−2.07	−59.14
K_2O	11.91	2.26	5.06	—	−6.85	−57.21
H_2O	.18	14.20	31.76	+31.58	—	large gain
Total	100.00	100.00	223.68	+132.60	−8.92	
	Albite					
SiO_2	65.85	70.02	125.83	+59.98	—	+91.09
Al_2O_3	21.35	11.88	21.35	—	—	—
CaO	1.73	.37	.67	—	−1.06	−61.27
Na_2O	10.24	2.73	4.91	—	−5.33	−52.05
K_2O	.56	.23	.41	—	− .15	−26.79
H_2O	.27	14.77	26.54	+26.27	—	large gain
Total	100.00	100.00	179.71	+86.25	−6.54	
	Kunzite					
SiO_2	64.12	61.09	88.23	+24.11	—	+37.60
Al_2O_3	27.99	19.38	27.99	—	—	—
Na_2O	.18	.04	.06	—	− .12	−66.67
K_2O	.05	.04	.06	—	—	—
Li_2O	7.61	2.92	4.22	—	−3.39	−44.55
H_2O	.05	16.53	23.87	+23.82	—	large gain
Total	100.00	100.00	144.43	+47.43	−3.51	

A. Analyses of minerals used recalculated to total 100 per cent.

B. Analyses of residues recalculated to total 100 per cent.

C. Column B recalculated on the assumption of no loss or gain of Al_2O_3. In the case of microcline, for example, the oxides in column B are multiplied by $\frac{19.08}{8.53}$.

D. Gains in parts by weight per 100 parts of the fresh mineral (*C* minus *A*).

E. Losses in parts by weight per 100 parts of the fresh mineral (*C* minus *A*).

F. Losses (−) and gains (+) of each constituent in parts by weight per 100 parts of the constituent in the fresh mineral $\left(\frac{D \text{ or } E}{A}\times 100\right)$.

$>Al_2O_3$. The kunzite was least altered; it lost only 44 per cent of its lithia.

Carbon dioxide was not found in the residues. Therefore, the loss on ignition has been attributed to water. In an attempt to determine if the water was adsorbed or if some of it had become a part of the lattice of a hydrous silicate, the residues were dehydrated at various temperatures. Dehydration curves plotted from these data (Fig. 1) show that approximately one-half of the water could not be expelled by heating the residues at 100° C.; some of it still remained at 500° C. The curves are quite smooth, indicating that the water was held essentially in the same manner at high as at low temperatures.

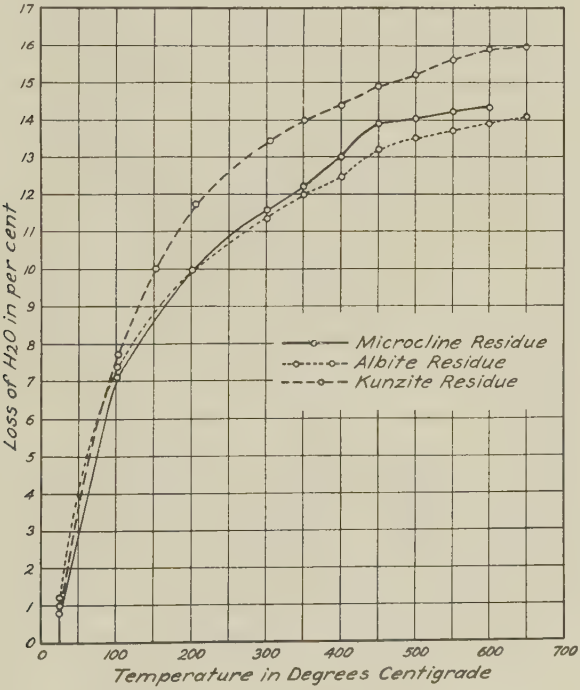

FIG. 1. Dehydration curve of finely ground and electrodialyzed microcline, albite, and kunzite.

Clay minerals, such as kaolinite, have dehydration curves with inflections which show the temperature at which crystal lattice water is liberated. However, as Kelly, et al.[22], have pointed out, these inflections are less pronounced when the clay minerals are finely pulverized. This effect has been ascribed to adsorbed water and to the probability that lattice water is more readily expelled from very tiny particles. Samples of

[22] Kelly, W. P., Jenny, Hans, and Brown, S. M., Hydration of minerals and soil colloids in relation to crystal structure: *Soil Sci.*, **41**, 259–274 (1936).

Morton kaolinite[23], dehydrated before and after grinding, gave curves (Fig. 2) which agreed closely with the work of these investigators. The shape of the dehydration curve of the kaolinite approached that of the residues as it was ground finer. In view of this fact, the dehydration data are considered to be inconclusive, but it seems probable that most of the water was merely adsorbed on the residue particles.

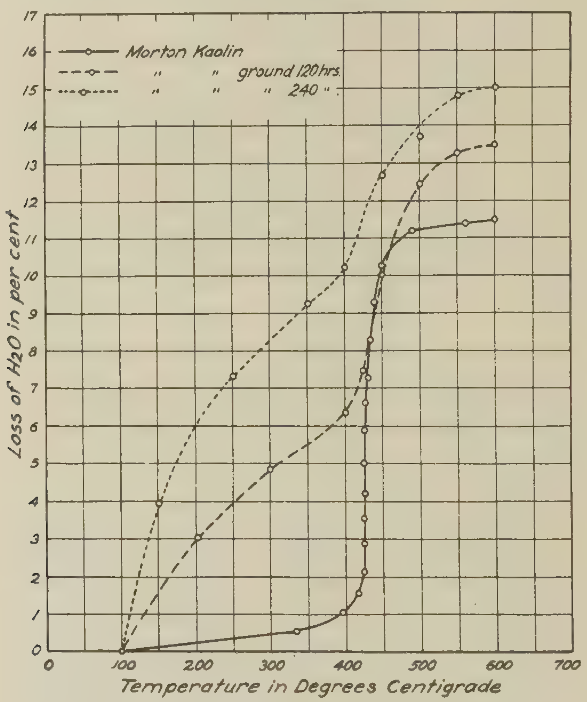

FIG. 2. Dehydration curves of Morton kaolin.

X-RAY DATA

Mineral Residues. X-ray patterns of the microcline, albite, and kunzite residues were essentially the same as those obtained from the fresh minerals, showing that no detectable new mineral had been formed. The lines on the patterns, however, were much broader and more diffuse, and some of the lines from weak reflections in the minerals were entirely lacking in the residue patterns. The broadening of lines on an x-ray powder diagram becomes very marked when the mineral particles are approximately 0.01 micron in diameter.[24] From this effect, it was estimated[25] that the residues had a grain size ranging about between 0.1 and 0.02 micron. The kunzite residue was the most coarse-grained; its grain size was probably near the coarser limit of this range. Although large amounts of agate were added to the residues from the mortar and pestle, no quartz lines could be detected in the x-ray photographs. It was probably present in particles less than 0.01 micron in diameter, which would be too fine-grained to reflect the x-rays.

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[23] For description and analysis of Morton kaolinite see Grout, F. F., and Soper, E. K., Clays and shales of Minnesota: *U. S. Geol. Survey., Bull.* **678,** 219 (1919).

Bomb-treated Residues. The residues were treated in 20 cc. of distilled water at 300°C. in a gold-lined, steel bomb with a capacity of 50 cc. The new lines, which appeared on the x-ray photographs after this treatment, are given in Table 4. The albite and kunzite were subjected to these conditions for 7 and 8 days, respectively, and similar experiments with these materials for 16 days yielded the same results. The line at $d = 3.349$ Å appeared on the microcline residue pattern after hydrothermal treatment for 7 days, but the other two lines did not appear until the residue had been maintained at 300° C. for 18 days. Some of the lines which were missing on the photographs of the residues reappeared after the hydrothermal treatment, and all lines were less diffuse, suggesting that there may have been a small increase in the size of the particles of the original minerals.

TABLE 4. INTERPLANAR DISTANCE, d, OF NEW LINES IN THE X-RAY PHOTOGRAPHS OF THE RESIDUES AFTER HYDROTHERMAL TREATMENT AT 300°C.

Microcline Residue (18 days)		Albite Residue (7 days)		Kunzite Residue (8 days)	
d in Å	*I**	*d in Å*	*I*	*d in Å*	*I*
4.463	vw	4.457	vw	4.463	vw
3.349	m	3.342	m	3.358	m
				2.555	w
				1.828	w
1.492	m	1.489	m	1.492	m

* I = Intensity; vw—very weak; w—weak; m—moderate.

Since the most intense line of quartz would occur at $d = 3.33$ Å, the line at about that position in the patterns has been assigned to quartz, formed from silica derived either from the minerals or from the agate mortar. The other lines agree closely with some of the strong lines of kaolinite. The line at $d=1.49$ Å is particularly characteristic of kaolin minerals and similar layer structures. Two of the most characteristic lines of kaolinite would be produced by reflections from the basal pinacoid and should appear at $d=7.16$ and 3.58 Å. These lines were not detected on the photographs. Somewhat unequal spacings of the layers may be an explanation for the lack of strong reflections from the basal pinacoid.

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[24] Bragg, W. H., and W. L. *The Crystalline State*, G. Bell and Sons Ltd., London, 188 (**1933**).

[25] Gruner, J. W., Personal communication (1937).

Summary

Samples of microcline, albite, and kunzite were reduced to particles less than 0.1 micron in diameter by grinding in water in an agate mortar for 394 hours or more. The suspensions produced were electrodialyzed in the mortar to remove bases. It was found that all of the constituents of the minerals diffused through the membrane of the dialyzer. This was interpreted as evidence that all of the constituents were present in solution in the ionic state, and that clay minerals may form, at least in part, by ionic reactions.

The feldspars lost more than 50 per cent of their alkalis. The rate of solution of the components of the feldspars was: $CaO > Na_2O > K_2O > SiO_2 > Al_2O_3$. Silica was dissolved more readily from the albite than from the microcline. The kunzite lost 44 per cent of its lithia and small amounts of silica and alumina.

The decomposed minerals were considerably hydrated. About 50 per cent of the water could not be expelled at 100°C., and a small amount of water was still retained at 500°C. Some of the water may be attributed to hydration of relatively large amounts of silica introduced from the agate mortar and pestle. Dehydration curves of the decomposed minerals were essentially smooth, suggesting that much water was probably present as adsorbed water and not as crystal lattice water.

X-ray investigations revealed that substantial amounts of feldspars and kunzite remained in the residues after grinding and dialysis. No evidence of the formation of a new mineral could be detected in the *x*-ray photographs.

After treatment of the decomposed minerals in water at 300°C., *x*-ray photographs displayed a new line indicating the formation of quartz. Other new lines suggested the formation of kaolinite or of a similar layer structure. The feldspar and kunzite lines were more intense, suggesting that the particles of these minerals increased in size during the hydrothermal treatment.

NOTE ON DETERMINATION OF OPTIC AXIAL ANGLE AND EXTINCTION ANGLE IN PIGEONITES

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During the past decade the work of several petrologists on the course of crystallization of pyroxene in basic magmas has drawn attention to the importance of estimating accurately the composition of augites occurring in basalts and dolerites (e.g., see T. F. W. Barth,[1] W. Q. Kennedy[2] H. Kuno[3]). Determination of 2V and the extinction angle is an essential part of such estimations (cf. Deer and Wager[4]) and should be carried out as accurately as possible. In pigeonites of low axial angle ($2V=0°–20°$) which give sensibly uniaxial interference figures in convergent light, it is difficult to determine the exact positions of X, Y and Z if the standard universal stage procedure, as described for example by Nikitin,[5] is followed. As a result of close approach to the uniaxial condition, any direction in the plane XY (perpendicular to Bx_a) has properties that approximate to those characteristic of a principal axis of the indicatrix. If any such direction is placed parallel to the EW axis (A_4) of a universal stage, the section remains approximately in extinction when tilted about that axis. Further, if the stage is now rotated into the 45° position and the section is again tilted on the EW axis, near-extinction is achieved over a short arc of rotation as the optic axes approach, but not necessarily attain, parallelism with the vertical axis of the microscope.

To overcome the resulting ambiguity as to the location of X and Y, the writer has found the following procedure effective. Select a crystal showing interference tints of a low order—preferably one in which the salite structure, orthopinacoidal twinning or two sets of cleavages are developed. Set the inner circle of the stage at any convenient reading (say, 20°) and tilt about the NS axis (A_2) so as to bring some direction in the XY plane parallel to the EW axis; the interference colour falls as extinction is approached, and the section remains almost or quite dark on subsequent tilting about the EW axis. The optical reaction is sharp, and the requisite tilt on NS can be determined to within less than one degree.

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[1] Barth, T. F. W., The crystallization process of basalt: *Am. Jour. Sci.*, **31**, 321–351 (1936).

[2] Kennedy, W. Q., Trends of differentiation in basaltic magmas: *Am. Jour. Sci.*, **25**, 239–256 (1933).

[3] Kuno, H., On the crystallization of pyroxenes from rock magmas with special reference to the formation of pigeonite: *Jap. Jour. Geol. and Geog.*, **13**, 141–150 (1936).

[4] Deer, W. A., and Wager, L. R., Two new pyroxenes included in the system clinoenstatite, clinoferrosilite, diopside and hedenbergite: *Min. Mag.*, **25**, 15–22 (1938).

[5] Nikitin, W., *Die Fedorow-Methode,* Berlin, Borntraeger, 31–38 (**1936**).

Now rotate on the inner vertical axis through successive intervals of 20° or 30° and repeat the above procedure for each position of the section, provided that the tilt on the EW axis does not exceed about 35°. The points so obtained (poles of lines in the plane XY) are now plotted on a stereographic net,[6] preferably using the lower hemisphere of projection, and they will be found to lie on a great circle of the net (AA in Fig. 1). If any point departs from the circle, the discrepancy is due to error in measurement, and the corresponding axis should be measured again. The acute bisectrix Z is perpendicular to the great circle so determined and can now be plotted. The writer finds that Z can be located more accurately by this method than by direct measurement, especially since in sections suitable for measuring 2V the direct method must involve high angles of tilt on the NS axis.

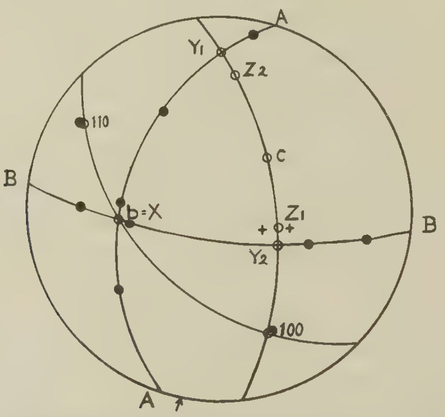

FIG. 1. Stereographic projection (lower hemisphere) of twinned pigeonite from diabase, West Rock, New Haven, Connecticut. Solid circles = observed points; open circles = deduced points; crosses adjacent to Z_1 = observed points of emergence of optic axes in the first half of the twinned crystal.

The positions of X and Y have now to be determined. One of these directions is perpendicular to (010), while the other is parallel to (010), so that if this latter plane is located and plotted its intersection with the plane XY will be either X or Y, usually the former. To do this it is necessary to measure either (a) the basal plane as indicated by salite structure, or (b) the twinning-plane (100) and corresponding twinning axis *c* in orthopinacoidal twins, or (c) the intersection of two sets of prismatic cleavages.

(a) If salite structure is present, as is commonly the case with pigeonite in dolerites, the position of (001) can be observed directly, usually with great accuracy on account of the sharp definition of the planes of parting involved. Its pole is plotted on the projection and the great circle (010) is drawn through this pole and the pole of Z.

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[6] A Schmidt equal-area net will do equally well.

(b) When the crystal shows orthopinacoidal twinning, the position of Z is determined in both halves of the crystal, and the twinning plane (100) is observed directly. The poles of Z_1, Z_2 and (100) should lie on the great circle (010). This is probably the most accurate of the three methods.

(c) The prismatic cleavages are usually less sharply defined than the basal parting, and their positions can therefore be determined only to within one or two degrees. Their intersection on the projection gives the position of the *c* axis to within about 3°, and the great circle through this point and Z is (010).

On the great circle perpendicular to Z the poles of X and Y lie at the intersection with (010) and the point 90° distant from this. By rotation on the inner circle and tilting about the NS axis of the stage, bring one of these axes parallel to the EW axis. Rotate the whole stage into the 45° position using the vertical microscope axis, then tilt to extinction (or near-extinction) on the EW axis. If the crystal axis in question is X, a narrow zone of near-extinction is attained as the acute bisectrix Z is brought parallel to the microscope axis. If the crystal axis is Y, then extinction prevails over a wider arc of tilting as first one optic axis and then the other is brought parallel to the vertical axis of the microscope. In this case the axial angle 2V can be measured directly. If the value of 2V is greater than about 10° a zone of very faint illumination can usually be distinguished between the axial points, but for smaller values of 2V there is darkness over the whole arc between the optic axes.

The extinction angle $Z \wedge c$ may be determined by direct measurement from the projection (see Fig. 1):

(a) Where (001) has been plotted, $Z \wedge c =$ the angle between Z and the pole of (001) plus 16° (since in augites the crystallographic angle $\beta = 74°$).

(b) In twinned crystals the bisectors of the angles between Z_1 and Z_2 are the *c* axis and the normal to (100), respectively. The extinction angle $Z \wedge c$ is thus one-half the appropriate angle $Z_1 \wedge Z_2$ (cf. T. Nemoto[7]). This is probably the most accurate method of determining $Z \wedge c$.

(c) If no crystals showing salite structure or twinning are available, $Z \wedge c$ is best determined in a section approximately parallel to the plane (010). Here the position of Z is measured directly and *c* is given by the trace of the vertical cleavages.

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[7] Nemoto, T., A new method of obtaining extinction angle of monoclinic minerals, especially of pyroxenes and amphiboles, by means of random sections: *Jour. Fac. Sci. Hokkaido Imp. Univ.*, (4), **4**, 107–111 (1938).

In order to obtain the composition of the pigeonite under consideration it is of course still necessary to determine either refractive indices or birefringence.

As an example, measured data are given for a twinned crystal of pigeonite in diabase from West Rock, New Haven, Conn., in which pigeonite is associated with a normal augite having $2V=42°–56°$. The readings cited are those for which the measured direction or plane is parallel to the EW axis of the stage; if the measured element is a plane it is also parallel to the vertical axis of the microscope. Tilts on the NS axis from the right-hand side are recorded thus ←; tilts on the EW axis away from the observer are indicated thus ↑.

	Measured Direction or Plane	Reading on Inner Circle	Tilt on NS Axis	Tilt on EW axis
First half of crystal.	Directions in Plane XY	8°	35°→	
		50	22→	
		90	4←	
		130	28←	
	Twinning-plane (100).	34	0	22° ↑ (±3)
	Cleavage (110).	70	0	8 ↓ (±3)
Second half of crystal.	Directions in Plane XY	20	38→	
		10	18→	
		0	13←	
		350	36←	
	Z	274	18→	
	Cleavage (110).	70	0	8 ↓ (±3)

From the projection based on these data (Fig. 1) the positions of various crystallographic directions may be read as follows:—

Crystallographic Direction	Reader on Inner Circle	Tilt on NS Axis
b (=X_1 and X_2)	18°	34°→
c	58	49←
Y_1	279½	11→
Y_2	341	50←
Z_1	354	54←
Z_2	274	19→

Extinction angle $Z\wedge c=40°$.
Optic axial plane transverse to (010).

2V (measured with Y_1 parallel to the EW axis of the stage) $= 14°$ (± 2).

Applying these data to the diagram of Deer and Wager,[8] two alternative compositions are possible for the pyroxene in question, viz., $Wo_6En_{50}Fs_{44}$, or $Wo_{10}En_{67}Fs_{23}$. The birefringence ($\gamma-\alpha$) determined with a Berek compensator, assuming birefringence of 0.007 for an adjacent crystal of labradotite (An_{57}), is 0.026. This favors the composition $Wo_6En_{50}Fs_{44}$.

The accuracy of the data obtained in the above-described investigation can be checked to some extent by plotting the observed cleavages parallel to (110). The angle between the pole of (110) and *b* should be 43°35′; that between the pole of (110) and *c* should be 79°10′; the angle measured on the projection between *b* and the pole of the observed cleavage (110) is actually 43°, though the latter departs slightly from the great circle perpendicular to *c*.

As a further check on the position of the axial plane, $\gamma-\beta$ was determined with a Berek compensator as .0245, as compared with $\gamma-\alpha = .026$. This corresponds to $2V =$ about 22°, using the Boldyrew chart as given by Nikitin.[9]

The same procedure on a second twinned crystal gave the following results: $2V = 20°$; axial plane perpendicular to (010); $Z \wedge c = 39°$; $\gamma-\alpha = .027$.

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[8] *Loc. cit.*, 22, Fig. 3.

[9] *Loc. cit.*, pl. IV.

NOTES AND NEWS

LAMPROBOLITE, A NEW NAME FOR BASALTIC HORNBLENDE

Austin F. Rogers,
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In recent years the amphibole with high ferric iron content, high indices of refraction, and rather strong to extreme birefringence has often been regarded as a distinctive mineral of the group under the name basaltic hornblende. Weinschenk, Johannsen, Tickell, Schmidt and Baier, Chudoba, Angel and Scharizer, Rogers and Kerr, and probably others have so considered it. Many petrographers working on the detrital minerals of oil-field sediments have listed it separately from ordinary hornblende.[1] There are cogent reasons for separating it from common hornblende. In addition to the differences mentioned above, it has strong pleochroism, a small extinction angle ($c\wedge\gamma=0$ to 10°), subadamantine luster, and usually a short prismatic habit. It is easily distinguished from common hornblende of brown color in both thin sections and crushed fragments.

Next let us consider the name for the particular amphibole in question. The term basaltic hornblende is unsatisfactory for three reasons: (1) It is a double name and too long. The tendency for sometime has been to reduce double names of minerals to single names; for example, nitratine was introduced to replace "soda niter." (2) It is by no means limited to basalts and basalt tuffs, but is common in other kinds of extrusives, such as trachytes, andesites, auganites, basanites, tephrites, and the corresponding tuffs. (3) It is not strictly speaking a hornblende, that is to say, hornblende in my opinion should be defined so as to exclude basaltic hornblende. If this be done, then "hornblende" replaces "common hornblende" and thus another double word is eliminated from the list of mineral species.

What other names have been used for this interesting amphibole? Kirwin, early English mineralogist, introduced the name "basaltine" for basaltic hornblende, but in recent years Milner,[2] as far as I know, is the only one who uses the term. According to Chester,[3] basaltine (von Born, 1790) is a synonym of augite, but it has also been used as a general term to include both basaltic hornblende and basaltic augite. It is obviously not a suitable name for the mineral under discussion.

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[1] For example, it had a place on the printed sheets "Heavy Mineral Determinations" used by the late Dr. Ralph D. Reed in the Research Laboratory of the Marland Oil Co. in San Francisco about 1925.

[2] *Sedimentary Petrography*, 3d ed., p. 250, London (1940).

[3] *Dictionary of the Names of Minerals*, p. 27, Wiley, New York (1896).

In 1932 Winchell[4] proposed the term "oxyhornblende" as a substitute for basaltic hornblende. Barnes,[5] working under Winchell's direction, proved conclusively that ordinary green hornblende is changed to a brown substance much resembling basaltic hornblende. The ferrous iron is oxidized to ferric iron by a loss of hydrogen (rather than by gain of oxygen) without destruction of the space lattice. The results brought about by heating common green hornblende have been known for half a century, but it remained for Barnes to determine the true nature of the change.

It was suggested by Miers[6] that the properties of basaltic hornblende are "acquired characters." This point has been emphasized by Winchell, and the evidence now seems to be complete that basaltic hornblende is formed from ordinary hornblende by a partial oxidation of the iron. The writer[7] has expressed the opinion that this oxidation was brought about by "hot gases at a late stage in the magmatic history." But whatever its origin may be, the properties of basaltic hornblende are sufficiently characteristic for it to be regarded as a distinct mineral. Winchell's name, as well as the name basaltic hornblende, implies that it is a mere variety of hornblende.

The writer proposes the name *lamprobolite* (lam-pro-bōl′ite) for the amphibole under discussion. It is derived from the Greek λαμπρός, shining or lustrous, and βολίς, a missile. The stem, *lampro-*, appears in the mineral names, lamprophyllite, lamprophanite, and chalcolamprite, and in the rock name, lamprophyre. The stem *bolid-* is found in bolide (a brilliant meteor). The shortened form *bol-*, however, is preferable for compounding and is suggested by the stem found in amphibole. The new name is appropriate since crystals of the mineral have high vitreous or subadamantine luster (especially on fresh cleavage surfaces) lacking in other amphiboles, and since the most typical specimens such as those from the basaltic tuffs of the Bohemian Mittelgebirge[8] (Lukow is a prominent locality) are volcanic ejectamenta.

For a mineral which has been known for more than a century, one hesitates to give an entirely new name unrelated to previous names. But while lamprobolite is a distinctive name, its sound especially suggests that it may be an amphibole.[9] The accent on the third syllable (lam-pro-bol′ite) will distinguish it from amphibolite (am-fib′o-lite).

[4] *Am. Mineral.*, **17**, 472–473 (1932).

[5] *Am. Mineral.*, **15**, 393–417 (1930).

[6] *Mineralogy*, p. 427, Macmillan, London (**1902**).

[7] *Introduction to the Study of Minerals*, 3d ed., p. 455, McGraw-Hill, New York (**1937**).

[8] Hibsch, J. E., *Die Minerale des Böhmischen Mittelgebirges*, Gustav Fischer, Jena (**1934**).

[9] The variant, lamprobole, though more euphonious, is too much like amphibole and might easily be confused with it.

Synonyms from the time of Werner to the present are listed here, but there may be others that have been overlooked.

SYNONYMS OF LAMPROBOLITE

Basaltische hornblende, Werner (1789).
Basaltine, Kirwan (1794).
Amphibole crystallisée, Haüy (1801).
Amphibolus basalticus, Breithaupt (1820) (?).
Hornblende ferrifère, Lévy and Lacroix (1888).
Oxyhornblende, Winchell (1932).
Lamprobolite, Rogers (1940).

In this compilation, the excellent work of Hibsch,[10] doubtless to become a classic, has been very useful.

DATA FOR LAMPROBOLITE[11]

Monoclinic prismatic class.
Usual forms: *m*{110}, *b*{010}, *r*{111}, *p*{$\bar{1}$01}. Twin-plane = {100}.
Habit: usually short prismatic.
Cleavage parallel to *m*{110}. $(110 \wedge 1\bar{1}0) = 55°42'$ (St. Kreutz).
Color: black, but translucent brown on thin edges.
Luster: high vitreous or subadamantine.
Axial plane = {010}, $c \wedge \gamma = 0$ to 12° (in the obtuse angle β); $2V = 64°$ to 80°. Opt. (−).
Pleochroism strong; α = light yellow, β = brown, γ = dark red-brown; $\gamma > \beta > \alpha$.
Indices: $n_\alpha = 1.670$ to 1.692; $n_\beta = 1.683$ to 1.730; $n_\gamma = 1.693$ to 1.760.
Birefringence: $n_\gamma - n_\alpha = 0.026$ to 0.072.
Occurrence: In mediosilicic to subsilicic volcanic extrusives and the corresponding tuffs. Also as a detrital mineral.
Origin: Formed from common hornblende by the partial oxidation of iron which is probably due to hot gases at a late magmatic stage.

In conclusion, I must record my obligation to my colleague, Professor Raymond D. Harriman of the Department of Classics, for his interest in the new name here proposed. Like many another scientist I have had "small Latin and less Greek."

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[10] *Op. cit.*

[11] According to St. Kreutz (in Hibsch, *loc. cit.*, p. 99) the variability in the optical properties of basaltic hornblende is due to variation in the oxidation of the iron.

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SCHEDULE OF PRESENTATION OF PAPERS

AFTERNOON SESSION

Thursday, December 26, 1940 Room 315–316, Students Union Building

Chairman: Wiiliam F. Foshag

1	2:30	A. Pabst	The unit cell and space group of gillespite. (15 minutes; lantern slides)
2	2:50	E. H. Kraus and C. B. Slawson	Role of hardness and structure in the shaping and use of industrial diamonds. (15 minutes; lantern slides)
3	3:10	A. N. Winchell	The spinel group. (10 minutes)
4	3:25	A. F. Rogers	Lamprobolite, a new name for basaltic hornblende. (10 minutes)
5	3:40	J. D. H. Donnay	Interference figures in convergent light. (10 minutes; lantern slides)
6	3:55	R. M. Dreyer	The problem of the variation in cinnabar coloration. (7 minutes; lantern slides)
7	4:07	E. H. Kraus and C. B. Slawson	An interesting distorted diamond crystal. (5 minutes; lantern slides)
8	4:17	C. W. Wolfe	Unit cell of dickinsonite. (8 minutes)
9	4:30	E. D. Taylor	Optical properties of cleavage flakes. (10 minutes; lantern slides)
10	4:45	C. Frondel	Whitlockite: a new calcium phosphate, $Ca_3(PO_4)_2$. (6 minutes)
11	4:56	A. P. Smith	Olivine and pyroxene of Mt. Tripyramid, New Hampshire. (5 minutes; lantern slides)
12	5:06	L. S. Ramsdell	The gnomonic projection in the hexagonal system. (10 minutes; lantern slides)
13	5:21	P. F. Kerr and Ford Young	A new hydrous tungsten oxide from Oruro, Bolivia. (5 minutes; lantern slides)
14	5:31	J. D. H. Donnay	Representatives of the brookite space-group. (10 minutes; lantern slides)
15		L. G. Berry	The structural cell of jordanite. (Presented by title)
16		C. Faessler	Petrographic study of the new Mont Laurier—Senneterre highway (preliminary report). (Presented by title)
17		C. Frondel	Constitution and polymorphism of the pyroaurite and sjogrenite groups. (Presented by title)
18		C. Frondel, W. H. Newhouse, and R. F. Jarrell	Spatial distribution of minor elements in single crystals. (Presented by title)
19		W. K. Gummer	A study of the border rocks of a granite batholith, Red Lake, Ontario. (Presented by title).
20		R. J. Holmes	The nature of arite. (Presented by title)
21		M. A. Peacock	Joseite from British Columbia. (Presented by title)
22		D. R. E. Whitmore	The chrome micas. (Presented by title)

AFTERNOON SESSION

Friday, December 27, 1940 **Room 315-316 Students Union Building**

Chairman: Max N. Short

Geological Society of America—Mineralogical Society of America

1	2:00	A. F. Rogers	Nephrite jade from Monterey County, California. (10 minutes; kodachrome slides)
2	2:15	E. E. Wahlstrom	Hydrothermal deposits in the Specimen Mountain volcanics, Colorado. (10 minutes; lantern slides)
3	2:30	R. D. Butler and L. B. Riley	Ore-bearing pipes in the Tarryall Range, Colorado. (10 minutes; lantern slides)
4	2:45	V. E. Barnes	Tektites. (10 minutes; lantern slides)
5	3:00	H. H. Nininger	The moon as a source of tektites. (10 minutes)
6	3:15	Alonzo Quinn	Igneous rocks of the Copple Crown-Merrymeeting Lake area of New Hampshire. (10 minutes; lantern slides)
7	3:30	C. J. Roy and Jacob Freedman	Petrology of the Pawtuckaway Mountains, New Hampshire. (10 minutes)
8	3:45	L. R. Page	The igneous and metamorphic rocks of the Rumney quadrangle, New Hampshire. (10 minutes; lantern slides)
9	4:00	A. P. Smith	Perthite from central New Hampshire. (10 minutes; lantern slides)
10	4:15	P. F. Kerr and W. W. Lomerson	An occurrence of pinite rock. (10 minutes; lantern slides)

AUTHOR—TIME INDEX

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Barnes, Virgil E.	Friday	2:45 P.M.
Berry, Leonard G.	by title	
Butler, Robert D.	Friday	2:30 P.M.
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	Thursday	5:31 P.M.
Dreyer, Robert M.	Thursday	3:55 P.M.
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Kraus, Edward H.	Thursday	2:50 P.M.
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Page, Lincoln R.	Friday	3:45 P.M.
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Quinn, Alonzo	Friday	3:15 P.M.
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Taylor, Edward D.	Thursday	4:30 P.M.
Wahlstrom, Ernest E.	Friday	2:15 P.M.
Whitmore, Duncan R. E.	by title	
Winchell, Alexander N.	Thursday	3:10 P.M.
Wolfe, C. W.	Thursday	4:17 P.M.
Young, Ford	Thursday	5:21 P.M.

TEKTITES*

VIRGIL E. BARNES

Tektites are etched pebbles of acidic glass mostly black and lustrous in reflected light and bottle-green, smoky, or brown in trasmitted light. They are found in siliceous gravels of Miocene to Pleistocene age. Tektites are found in Czechoslovakia, Australia, Indo-China, Philippine Islands, Dutch East Indies, Siam, China, Ivory Coast, and possibly in South America. In North America, tektites were recognized first in 1936 (Univ. Texas Pub. 3945, pp. 477–582, 1940).

Tektites have an excellent flow structure outlined by adjacent schlieren of different chemical compositions. These heterogeneous glasses etch differentially producing the weathered surface distinctive of tektites. In obsidian the flow structure is outlined by crystallites and vesicles and not by difference in composition of the glass; consequently etched obsidian is free of fine flow lines and resembles tektites only in the coarser etch markings.

Tektites definitely are not of an igneous origin. This fact led indirectly to the prevalent assumption that they are meteorites. Chemically tektites correspond closely to elastic sedimentary rocks ranging from shale to sandstone in composition. The writer identified small included glass particles in tektites as lechatelierite. These lechatelierite particles must have been originally grains of quartz or other non-hydrous silica. These grains were melted during the process of tektite formation. Their presence probably excludes a meteoritic origin.

Lightning may produce tektites. Glass formed by power line short circuits through soil contains lechatelierite particles. This glass very closely resembles tektite glass and when artificially etched develops a typical tektite-like surface. Observations of the effect of lightning upon elastic sedimentary rocks and their soils are needed.

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* Presented through the Geological Society of America.

THE STRUCTURAL CELL OF JORDANITE

L. G. BERRY

Single crystal x-ray photographs on a cleavage fragment (sp. gr. 6.44) from Binn, Switzerland, give a simple monoclinic lattice in which the cell with the shortest edges has the dimensions:

$$a_0\ 8.89 \pm 0.03,\ b_0\ 31.65 \pm 0.03,\ c_0\ 8.40 \pm 0.02;\ \beta\ 118°21'$$

Space group C_{2h}^2—$P2_1/m$ or C_2^2—$P2_1$. In this lattice the structural cell given by Richmond has the edges $a' = [\tfrac{1}{2}01]$, $b' = [010]$, $c' = [\bar{\tfrac{1}{2}}00]$. This cell is a half unit cell and is therefore inadmissible. The new cell content is:

$$Pb_{27}As_{14}S_{48} = 27PbS \cdot 7As_2S_3$$

with the calculated sp. gr. 6.49, rather than:

$$Pb_{28}As_{14}S_{49} = 7[4PbS \cdot As_2S_3]$$

This cell content, which is not divisible by two, reconciles the several half-cell contents obtained by Richmond (1938) and by Fisher (1940).

ORE-BEARING PIPES IN THE TARRYALL RANGE, COLORADO

ROBERT D. BUTLER AND L. B. RILEY

A number of small pipe-like deposits in red granite have been opened by prospectors on the western slope of the Tarryall Range. Their diameters range from five to eight feet and an ideal cross-section is circular, although it may be oval, semicircular, or rectangular. Metallic minerals present are: earthy hematite, pyrite, sphalerite, galena, chalcopyrite, and molybdenite. Gangue minerals are quartz, muscovite, and fluorite. Concentric alteration zones surrounding the pipes consist of bleached and silicified granite. Although pneumatolysis may have played a role in the formation of the pipes, an explanation involving only hydrothermal deposition is also tenable. The deposits resemble in most respects certain tin-bearing pipes in South Africa.

INTERFERENCE FIGURES IN CONVERGENT LIGHT

J. D. H. DONNAY

The usefulness of plans and elevations in the study of geometrical crystallography has been excellently demonstrated by A. F. Rogers (*American Mineral.* **8,** 19-31, 1923). The same methods of descriptive geometry can be applied with profit in optical crystallography, especially to the study of interference figures.

It is also proposed to use two meridional cross-sections, at right angles to each other and at 45° to the cross-hairs, through the surface of retardation. The *retardation curves* so obtained are helpful in explaining the motion of lines produced by the quartz wedge .(In the case of a biaxial crystal, sliced normal to the acute bisectrix, for instance, the *retardation curves* are drawn for the plane of the optic axes and for the plane of the acute bisectrix and the optic normal.)

REPRESENTATIVES OF THE BROOKITE SPACE-GROUP

J. D. H. DONNAY

The brookite space-group is D_{2h}^{15} (*Pcab* or *Pbca* according to crystal orientation). The morphological expression of this space-group is seen in the following characters: (1) No *double zone* is present. (2) All three central zones, [(*hkk*)], [(*lkl*]), [(*hhl*)], are *simple zones*, intersecting in a common dominant face, to be taken as (111). (3) All three axial zones, [(0*kl*)], [(*h*0*l*)], [(*hk*0)], are *simple zones* with dominant face "shifted" from unit position toward a pinakoid; the shifts are cyclic, either toward *c*, *a*, *b*, with dominant faces (012), (201), (120), respectively (orientation *Pcab*), or toward *b*, *c*, *a* with dominant faces (021) (102), (210) respectively (orientation *Pbca*).

These criteria need not all be present (as they are in *brookite**) to permit space-group identification. Thus, if only two central zones are developed, both simple, with a common dominant, the lattice is determined as primitive (examples: *scorodite, reddintite*). The unit-face (111) may be inferred from the dominant faces in the axial zones, using the rule that the dominant face in an axial zone must be either at unit distance, or at half the unit, or at twice the unit (examples: *hambergite,* sulfamic acid**). Very scant morphological information may suffice to point out the space-group (examples: *strengite, sulfamic acid,* oxalic acid**), especially if use be made of the generalization of the Law of Bravais.

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* For the species marked with an asterisk, the space-group has been determined by *x*-rays; it agrees with the morphological result.

THE PROBLEM OF THE VARIATION IN CINNABAR COLORATION

ROBERT M. DREYER

Cinnabar varies in color from orange red to dark purple. This variation in cinnabar coloration is independent of (1) the size of the cinnabar aggregates, (2) variations in crystal structure, (3) any spectrographically detectable quantitative or qualitative differences in elemental concentrations, and (4) the total impurity concentrated in solid solution in the cinnabar. The cause of the variation in cinnabar coloration therefore is, as yet, indeterminate.

PETROGRAPHIC STUDY OF THE NEW MONT LAURIER-SENNETERRE HIGHWAY

(Preliminary Report)

CARL FAESSLER

The new highway crosses over 100 miles of unexplored territory, from Mont Laurier (82 miles due north of Ottawa) northwest to the Abitibi mining district. It connects two formations of doubtful relative age: the Grenville limestone, in the south, and the Keewatin gold-bearing greenstones (altered lavas), in the north.

(1) For the first 20 miles, the highway shows the continuation of the typical Grenville crystalline limestone and garnetiferous paragneiss, which underlies the Mont Laurier area. (2) Then the limestone disappears completely, while another gneiss is encountered characterized as follows: absence of garnets, well-marked foliation, and evidence of granitization. This gneiss was followed by the author for 60 miles; Aubert de la Rüe[1] traced it 25 miles farther, clear to the Temiskaming sedimentary schists and graywackes, which border on the Keewatin of the Abitibi region. (3) Basic dikes cut through all rocks along the highway; more numerous toward the south, they trend south-east, toward a large anorthosite body (Morin series), of which they are considered offshoots.

The new gneiss reported may prove to be a migmatite, resulting from the alteration of a more argillaceous facies of the Grenville, with igneous additions. A source of magmatic liquid was available for the granitization, as proved by the presence nearby of acidic stocks (Pine Hill, Guenette, Labelle, Rolland), known to be differentiates of the main Morin intrusive.

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[1] Private communication.

CONSTITUTION AND POLYMORPHISM OF THE PYROAURITE AND SJOGRENITE GROUPS

CLIFFORD FRONDEL

The carbonate-hydroxides, pyroaurite, stichtite and hydrotalcite are shown by *x*-ray study to be isostructural. The dimorphism suggested by Aminoff and Broomé in 1930 for pyroaurite is definitely proven, and is shown to extend to stichtite and to hydrotalcite. Rhombohedral and hexagonal groups are recognized which each conform to the formula $R_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$, where R = Fe, Al or Cr. Data for the six species involved, three here being described as new, follows:

Rhombohedral or Pyroaurite Group

	Cell Contents (Hexagonal unit)	a_0	c_0	ω	ϵ	Proven Localities
Pyroaurite	$3(Fe_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.19	46.54	1.564	1.543	8
Stichtite	$3(Cr_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.18	46.38	1.545	1.518	3
Hydrotalcite	$3(Al_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.13	46.15	1.511	1.495	4

Hexagonal or Sjogrenite Group (New)

Sjogrenite	$Fe_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.20	15.57	1.573	1.550	1
Barbertonite	$Cr_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.17	15.52	1.557	1.529	3
Manasseite	$Al_2Mg_6(OH)_{16}CO_3 \cdot 4H_2O$	6.12	15.34	1.524	1.510	3

The structural cells found by single-crystal and powder *x*-ray methods have the cited values of a_0 and c_0 halved for the rhombohedral series and a_0 halved for the hexagonal series. The dimensions here given are required for rational cell contents. Dimensionally $c_{0(rh.)} : c_{0(hex.)} = 3:1$, and the halved value of a_0 for both series (*ca.* 3.1) is nearly identical with $a_0 = 3.12$ of brucite.

The minerals are lamellar on $\{0001\}$, often with a partially or completely random stacking of micro-crystals about $[0001]$. The rhombohedral and hexagonal analogues very commonly occur intimately admixed, and in part are mutually oriented in parallel position. Brugnatellite, $FeMg_6(OH)_{16}CO_3 \cdot 4H_2O$, is distinct from the minerals at hand, and the identity of houghite with hydrotalcite (actually manasseite) is confirmed. New localities for pyroaurite include Val Malenco and Val Ramazzo, Italy, and the first American occurrence, at Blue Mont, Maryland.

WHITLOCKITE: A NEW CALCIUM PHOSPHATE, $Ca_3(PO_4)_2$

CLIFFORD FRONDEL

Whitlockite is anydrous calcium triphosphate, $Ca_3(PO_4)_2$, with Ca substituted for by Mg (Mg:Ca=1:13) and Fe (Fe:Ca=1:17). Rhombohedral, probably scalenohedral—$\bar{3}\,2/m$, with $a:c=1:3.547$. Habit rhombohedral $\{10\bar{1}4\}$, with minor $\{0001\}$, $\{01\bar{1}2\}$, $\{11\bar{2}0\}$. Structure cell: $a_0=10.25\pm0.03$, $c_0=36.9\pm0.2$; $a_0:c_0=1:3.600$; $a_{rh}=13.65$, $\alpha=44°6\frac{1}{2}'$. Cell contents in the rhombohedral unit $Ca_{21}P_{14}O_{56}$. Space group (Weissenberg method) probably $R\bar{3}c$. No cleavage. Hardness 5. Specific gravity 3.12 (obsvd.), 3.19 (calc.). Colorless and transparent. Uniaxial—(neg.), with $\omega=1.629\pm0.002$, $\epsilon=1.626\pm0.002$ (for Na). The mineral is structurally distinct from graftonite and apatite.

Whitlockite occurs in the Palermo granite pegmatite near North Groton, New Hampshire, as a late hydrothermal mineral in the following association and sequence: whitlockite and quartz—rhodochrosite—apatite—zeolite. The mineral is named after Herbert P. Whitlock, a former president and secretary of this society and at present Curator of Minerals and Gems in the American Museum of Natural History.

SPATIAL DISTRIBUTION OF MINOR ELEMENTS IN SINGLE-CRYSTALS

C. FRONDEL, W. H. NEWHOUSE, R. F. JARRELL

It is shown spectrographically that the minor foreign elements present in single-crystals of galena, calcite and other species are not uniformly dispersed throughout the host crystal, but generally are distributed in adjoining or alternating regions of greater and lesser concentration. These concentration-regions are related to the growth surfaces of the host crystal, and fall into two types: (a) Pyramidal regions subjacent to particular faces on crystals bounded by several crystallographically different forms. The concentration differences arise in the unequal adsorptive capacity of the different forms on the growing crystal for the foreign elements in question. (b) Alternating bands parallel to the growth surfaces without any or marked selectivity as to the crystallographic kind of surface.

The spectrographic work on galena revealed that both Ag and Si are relatively concentrated in the growth regions subjacent to the octahedral faces of cubo-octahedrons. Other minor elements, including Cu, Fe, Al, Cr, Ba, Sr, Ca and Mg, show significant quantitative variations within galena single-crystals but apparently without any special relation to the morphology. Staining of sectioned and polished single-crystals develops a complex internal structure outlined by relatively reactive, dark stained, growth bands and segments. Correlated spectrographic examination indicates that the dark stained regions are enriched in Ag. The growth history of crystals from many different localities shows a general similarity: an early stage of octahedral, Ag-poor, galena followed by the appearance and gradual increase of cube faces with the concomitant deposition of Ag-rich galena in bands or segments especially upon the octahedral faces.

Spectrographic examination of calcite single-crystals further illustrates the features of distribution found with galena. Significant compositional variations are found between successive growth zones in habit-invariant single crystals and between overgrown crystals of different habit. No special connection, however, could be traced between the morphology, color or growth history of the crystals and any of the foreign elements tested (Fe, Cu, Mn, Al, Sr, Mg).

The factors (temperature, concentration, pH, rate of growth, morphology, etc.) which determine the partition coefficient between the minor element content of the mother solution and the growing host crystal and their bearing on the minerogenetic interpretation of spectrographic and other analyses are discussed.

A STUDY OF THE BORDER ROCKS OF A GRANITE BATHOLITH, RED LAKE, ONTARIO

WILFRID K. GUMMER

Granites intrusive into volcanic rocks in the Red Lake area are commonly surrounded by a gradational zone of more basic rocks. The granite in such areas is rich in inclusions of gabbroic and dioritic composition. Inclusions are both rounded and angular and vary greatly in size; the more altered ones are the more faded. A detailed investigation of such an occurrence in the Mackenzie Island area was carried out and forms the basis of this paper.

The study of the petrography of the main granite of the Mackenzie batholith, of the volcanic rocks and of the intermediate or border rocks, has brought out several points which bear upon the origin of the border rocks. Most important is the formation in the granite and the border rocks of late potash minerals.

Rosiwal analyses were made on a suite of rocks passing from the main granite through the border facies into andesitic rock. Mineral and oxide components when plotted against silica yield curves indicating that the border rocks are truly intermediate between the granite and volcanic rock, in composition. The conclusion is reached that the border rocks are the result of contamination of the granite magma by the introduction of numerous inclusions of the country rock. Textures and mineralogical assemblages indicate reaction between the liquid and solid phases.

THE NATURE OF ARITE

RALPH J. HOLMES

Uncertainty has long existed concerning the validity of the mineral arite or the natural occurrence of intermediate members of the system Niccolite, NiAs—Breithauptite, NiSb. Intermediate members of this isomorphous series can be produced synthetically. Further x-ray study of synthetic intermediate members of this series and x-ray and microscopic examination of natural material from several occurrences including the type locality at Ar in the Pyrenees indicates that a mineral intermediate between niccolite and breithauptite exists in nature. It is believed that this material may be properly designated as arite.

AN OCCURRENCE OF PINITE ROCK

PAUL F. KERR AND WILLIAM W. LOMERSON

A large mass of sericite, samples of which invert to mullite on calcination, occurs in the Humboldt Range, Nevada. Associated with the sericite are alumino-silicates, which it is believed are responsible for the unusual thermal behavior. The mass is thought to have been originally a fine tuff or ash which has been altered by hydrothermal metamorphism to a rock consisting in large part of finely crystalline potash mica. The name pinite is suggested as a rock term to be applied to such a mass. The principal associated rock units of the area are rhyolitic volcanics of the Koipato formation overlain by the Middle and Upper Triassic Star Peak limestones. The pinitized zone lies near the crest of a northward trending ridge on the south side of South American Canyon just below the contact between the volcanics and the limestones in a member of the series similar to the Rochester trachyte of Knopf.

Topographic and geologic maps of the deposit have been prepared and laboratory examination has involved microscopic, *x*-ray, and chemical study.

A NEW HYDROUS TUNGSTEN OXIDE FROM ORURO, BOLIVIA

PAUL F. KERR AND FORD YOUNG

The oxidation of ferberite from this locality has resulted in the formation of two hydrous oxides of tungsten. Previous descriptions of the deposit have mentioned the occurrence of tungstite, $WO_3 \cdot H_2O$. Recent studies indicate that a second oxide is present. *X*-ray and optical examinations show that this material differs in structure from the recorded descriptions of tungstite and chemical investigation indicates that it contains two molecules of water. Since this mineral appears to be an intermediate product in the alteration of ferberite to tungstite and since it resembles tungstite in many of its physical properties, the name *hydrotungstite* is suggested.

AN INTERESTING DISTORTED DIAMOND CRYSTAL

EDWARD H. KRAUS AND CHESTER B. SLAWSON

A 5.1 carat industrial stone which is a distorted octahedron with "prismatic" development is described. The orientation and distribution of the natural etch figures on the various faces are discussed.

ROLE OF HARDNESS AND STRUCTURE IN THE SHAPING AND USE OF INDUSTRIAL DIAMONDS

EDWARD H. KRAUS AND CHESTER B. SLAWSON

The study of variation of hardness in the diamond in relation to the crystal structure has been extended to the shaping and use of industrial stones. The shaping of stones for diamond-set tools, as developed through experience, reveals that the hardest directions, or "ribs," are utilized. In the case of wire-drawing dies, present knowledge of the variation of hardness and of the structure of the diamond is not sufficiently drawn upon. Suggestions are made for the improvement of the drilling and shaping processes and for the better orientation of the stones which should tend to increase the usefulness of the dies. These suggestions involve a more scientific utilization of the hardness and structural properties of the diamond, that is, of its "structural strength."

THE MOON AS A SOURCE OF TEKTITES*

H. H. NININGER

Assuming that the lunar "craters" are of meteoritic origin, this paper suggests that tektites have had their origin in connection with the impacts which formed those craters.

Note is taken of the fact that meteorites would encounter the surface of the moon at their full interplanetary velocities. The absence of a lunar atmosphere would allow ejectamenta to leave their points of origin at velocities above the minimum velocity of escape from the satellite whose gravitational power is only one-sixth that of the earth. Some of the fragments so ejected reach the earth as tektites.

Possibly some of the recognized varieties of meteorites also have this origin.

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* Presented through the Geological Society of America.

THE UNIT CELL AND SPACE GROUP OF GILLESPITE

A. PABST

Gillespite, $FeO \cdot BaO \cdot 4SiO_2$, has been found in only two localities, in an erratic boulder in Alaska and in Mariposa County, California, with sanbornite, $BaO \cdot 2SiO_2$, and barium feldspar. Gillespite from both localities was examined by x-ray powder and single crystal methods. Identical patterns are obtainable from material of both sources.

The cell dimensions are a_0 7.50±0.01 Å and $c_0 = 16.05 \pm 0.01$ Å. If the cell content is $4FeBaSi_4O_{10}$, this corresponds to a density of 3.405, slightly higher than the directly determined value, 3.33.

Laue patterns confirm the tetragonal character reported by Schaller and indicate the Laue symmetry $D_{4h}-4/mmm$. All patterns show $hk0$ with $h+k$ even only. No other regular extinctions occur. This indicates the space group D_{4h}^7-P4/nmm.

Consideration of $hk0$ "reflections" shows that Fe and Ba are located on the 4 and $\bar{4}$ axes. Extreme weakness of odd layer lines on c-axis rotation patterns indicates a pseudocell having half the height of the true cell. Tetragonal Si_4O_{10} sheets parallel to (001) are the characteristic features of the structure. These sheets differ somewhat from any hitherto described but it is not yet possible to assign atomic positions with certainty.

As reported by Schaller, gillespite may be leached by hydrochloric acid with removal of iron and barium. There remain soft, pearly, flakes of hydrated silica retaining the shape and cleavage of the original particles. They remain uniaxial negative, but have much lower indices of refraction and the density is reduced to 2.0 or less, Laue, rotation and powder photographs of this material fail to show any diffraction effects.

THE IGNEOUS AND METAMORPHIC ROCKS OF THE RUMNEY QUADRANGLE, NEW HAMPSHIRE

LINCOLN R. PAGE

The igneous rocks of the Rumney quadrangle, located in west-central New Hampshire, belong to three magma series. The concordant Owls Head-Baker Pond complex, a member of the Oliverian magma series, apparently differentiated in situ. Regional deformation, probably late Devonian in age, granulated and crushed these rocks and developed an obscure secondary foliation across the primary igneous structure. The Bethlehem granodiorite gneiss and probably the Kinsman quartz monzonite, members of the New Hampshire magma series, were intruded during the late stages of this deformation. The youngest member of this series, the Concord granite, was emplaced by stoping and is clearly post-tectonic. The Three Ponds gabbro distorts the surrounding granodiorite gneiss suggesting that it made its chamber by distension of its walls rather than by the process of cauldron subsidence which is characteristic of other igneous masses of the White Mountain magma series. Pegmatite, aplite, and late lamprophyre and quartz porphyry dikes cut the older plutons and enclosing schists.

Two grades of metamorphic rocks are recognized in the area. Intermediate grade schists of the Ammonoosuc volcanics (Ordovician), Clough conglomerate and Fitch formation (Silurian) and Littleton formation (Devonian) crop out in the northwest part of the area. High grade sillimanite-mica and quartz-mica schists of the Littleton formation are typical of the central and eastern parts. At the contact of the Bethlehem granodiorite gneiss, garnet-diopside contact rock has developed in the Fitch formation. Retrograde metamorphism of the sillimanite schists was noted adjacent to the Concord granite.

JOSEITE FROM BRITISH COLUMBIA

M. A. PEACOCK

Clean fragments (sp. gr. 8.10±0.05) from several specimens of a mineral resembling tetradymite, from Glacier Gulch, Hudson Bay Mountain, near Smithers, B. C., give identical x-ray powder spectra. The pattern is identical with that given by joseite (sp. gr. 8.03) from San José, Minas Geraes, Brazil (type from the collection of A. Damour), "grünlingite" (sp. gr. 8.15) from Carrock Fells, Cumberland (type locality), and "oruetite" (sp. gr. 8.11) from Serranía de Ronda, Malaga, Spain (type locality). The pattern is different from those given by tetradymite—Bi_2Te_2S and tellurbismuth—Bi_2Te_3. Since the specimen from Brazil represents the material originally described by Damour (1845) and named joseite by Kenngott (1853), the materials from British Columbia, Cumberland and Spain are referred to this species.

Single crystal x-ray photographs on the Canadian material give a rhombohedral lattice:

a_{rh} 13.45, α 18°08′ (from a_0 4.24 ± 0.01, c_0 39.69 ± 0.06)

with no systematic omission of rhombohedral indices. With these elements the powder spectrum has been completely indexed. The existing relevant chemical analyses vary widely. The ideal content of the unit cell is probably $Bi_4(Te, S)_3$, which includes the composition Bi_4TeS_2 recently given by Warren and Davis for a mineral from Glacier Gulch resembling joseite.

IGNEOUS ROCKS OF THE COPPLE CROWN-MERRYMEETING LAKE AREA OF NEW HAMPSHIRE

ALONZO QUINN

The Copple Crown-Merrymeeting Lake area, like several other small areas in central New Hampshire, has considerable variety of rocks grouped together. Rock types here include, from oldest to youngest, felsite, diorite-gabbro, diorite, granite, quartz porphyry, and several dike rocks. Petrographically, they are related to the rocks of the White Mountain magma series of possible Carboniferous age. The variety of rock types indicates considerable differentiation of this magma.

The felsite may be extrusive, but the other rocks are intrusive. The intrusions cut sharply across the foliation and the contacts of the older rocks and are mainly in round or oval bodies. These relationships indicate a method of intrusion similar to that in nearby areas where ring-dikes and plug-like intrusions were formed.

THE GNOMONIC PROJECTION IN THE HEXAGONAL SYSTEM

LEWIS S. RAMSDELL

The implications of the G_1 and G_2 settings, used for gnomonic projections of hexagonal crystals, are made clear by constructing the unit cells from which the two projections are derived. This construction is carried out by means of the reciprocal lattice. It is shown that the G_1 setting is based on the simple structural cell, with the correct axial ratio c, whereas the G_2 setting is based on a triple cell, with an axial ratio $c_2 = c/\sqrt{3}$. This is contrary to the usage of Goldschmidt in his Kristallformen der Mineralien. The G_2 setting is commonly used for rhombohedral crystals, but the triple cell on which it is based has no direct relationship to the actual rhombohedral cell.

LAMPROBOLITE, A NEW NAME FOR BASALTIC HORNBLENDE

AUSTIN F. ROGERS

The amphibole with subadamantine luster, high indices of refraction, strong to extreme birefringence, marked pleochroism, small extinction angle, and high ferric iron content has been regarded as a distinctive mineral under the names basaltic hornblende and oxyhornblende.

The former name is objectionable since it is a double name and since it is found in many types of extrusive rocks other than basalts.

Both names are objectionable in that they imply that the mineral in question is a variety of hornblende, but I would define hornblende so as to exclude basaltic hornblende and then "hornblende" may replace "common hornblende."

For the reasons stated, I propose the name *lamprobolite* (lamp-ro-bol′it) from the

Greek, *lampros*, shining or lustrous, and *bolis*, a missile, for this mineral. The new name seems to be an appropriate one since the best specimens available are the black (deep brown on thin edges), euhedral to subhedral crystals with brilliant cleavage surfaces from the basaltic tuffs (volcanic ejectamenta) of Lukow, Bohemia.

NEPHRITE JADE FROM MONTEREY COUNTY, CALIFORNIA*

AUSTIN F. ROGERS

Nephrite jade of fair quality suitable for cutting and polishing has recently been discovered in Monterey County, California.

The color of the nephrite varies from light greenish gray to black; the best material is dark American green (Ridgway). It is identified as nephrite by optical tests, specific gravity, and a quantitative chemical analysis. The nephrite occurs in rolled pebbles and boulders of various sizes with a weight range from less than a gram up to a maximum of over 300 Kg.

It has not yet been found in place, but from the meager data available at the present, it is most likely from the Franciscan formation of the Santa Lucia Range. In all probability it is connected in some way with serpentine.

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* Presented through the Geological Society of America.

PETROLOGY OF THE PAWTUCKAWAY MOUNTAINS, NEW HAMPSHIRE*

CHALMER J. ROY AND JACOB FREEDMAN

The Pawtuckaway Mountains are located in Deerfield and Nottingham townships, Rockingham County, in southeastern New Hampshire. Rocks belonging to the White Mountain magma series, which is Mississippian in age, were intruded into the Winnepesaukee gneiss of the New Hampshire magma series, which is late Devonian in age. The intrusion formed as a circular mass of gabbro, diabase and diorite, which forced its way into the gneiss and bent foliation planes in the gneiss from the regional, northeast trend into partial parallelism with the igneous body. A foliation in the diabase and in one phase of the diorite body strikes parallel to the contact and dips inward. Injected into the more mafic rocks are bodies of fine-grained monzonite, of which the two largest bodies form a broken circle open to the southwest. A coarse-grained monzonite was later injected as the core of this arc, and a similar arc of coarse-grained monzonite surrounds the gabbro-diorite body on three sides and is also open to the southwest.

The Pawtuckaway Mountain rocks all formed from one parent magma which differentiated at depth. A porphyritic gabbro solidified against the gneiss walls as intruded magma differentiated in place into four types of diorite. The biotite, hornblende, pyroxene, and feldspar in the monzonites differ only slightly from those in the diorites.

Aplitic, monzonitic, and lamprophyric dikes cut all the major rock types. The aplitic dikes cut the lamprophyric dikes, but the relationship of monzonitic dikes to the other dikes is unknown.

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* Presented through the Geological Society of America.

OLIVINE AND PYROXENE OF MT. TRIPYRAMID, NEW HAMPSHIRE*

ALTHEA PAGE SMITH

Olivine gabbro on Mt. Tripyramid provides one field test for Bowen and Schairer's experimental findings on incongruent relations in the system MgO-FeO-SiO_2. The gabbro belongs to the post-lower Devonian White Mountain magma series of alkaline affinities. In the gabbro, the FeO/MgO ratio of olivine (58/42) and pyroxene (44/56) $CaMgSi_2O_6$-54%, $CaFeSi_2O_6$-27%, $MgSiO_3$-12%, $FeSiO_3$-7% is so high that no incongruent reaction by pyroxene on olivine would be expected. Inclusion of smooth, euhedral olivine grains in pyroxene confirms the postulate and indicates that crystallization proceeded with equilibrium. The expected absence of the silica enrichment which in other rocks is produced by incongruent reaction and fractional crystallization, is verified by the low quartz content of the intermediate rocks of the series.

Because of the crystallization with equilibrium, the olivine has a higher FeO/MgO ratio than the pyroxene, rather than either the lower ratio of many reaction-embayed olivines from other regions, or the equal ratio assumed in calculation of the norm.

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PERTHITE FROM CENTRAL NEW HAMPSHIRE*

ALTHEA PAGE SMITH

In the Mt. Chocorua area the post-lower Devonian intrusions of the White Mountain magma series contain four types of perthite. In type 1 albite-oligoclase is irregularly intergrown with alkali feldspar. Neither mineral follows planes of weakness in the other. One subtype forms borders on sodic oligoclase, the latter merging through increasingly sodic zones with the similarly oriented albite-oligoclase of the intergrowth. The latter is complex, containing patches of microperthite of type 2 within much of its homogeneous orthoclase. Proportions of albite-oligoclase and alkali feldspar vary. The latter continued crystallizing after completion of the intergrowth. Perthite of type 1 is believed to be of simultaneous, but not eutectic, crystallization.

Microperthite of type 2 forms borders on, and patches within feldspar intergrowth of type 1. Type 2 consists of albite in narrow, even-spaced, parallel plane lamellae in orthoclase. The regularity of intergrowth suggests exsolution.

In type 3, microperthite of type 2 contains albite dikelets which follow and widen planes of exsolution and, rarely, planes of cleavage. Part of this albite occupied open spaces and part replaced orthoclase.

In perthite of type 4, microcline is partially replaced by irregular blebs of albite. Rare euhedral grains of the latter suggest that this perthitization occurred as early as the deuteric, or interstitial, stage.

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THE SPINEL GROUP

A. N. WINCHELL

Graphs have been prepared showing the variations in composition and physical properties in some parts of the spinel group, so far as possible with available data. This leads to the conclusion that there are at least two parts of the group between which there is not continuous gradation in composition so far as now known.

OPTICAL PROPERTIES OF CLEAVAGE FLAKES

E. D. TAYLOR

The optical properties of cleavage flakes are good determinative characters. The *orientation of the cleavage plane* is a constant, and can be easily determined on inspection in convergent light. Obliquities of optical directions to the plane of cleavage can be measured by means of a calibrated eye-piece micrometer. Measuring the retardation Δ of a plate (Berek compensator) and determining its thickness (calibrated focusing motion of the microscope) are simple operations. The *birefringence of the cleavage*, $n'-n''=\Delta/t$, is thus easily obtained, with an error of only one, or less, in the third decimal place. The *refractive indices of the cleavage*, n' and n'', can be measured, by the usual immersion method, without any rolling of grains. Pleochroic colors displayed by a cleavage plate are most easily ascertained.

Although the study of cleavage flakes has long been used, especially by French mineralogists, as a check in mineral identification, only one attempt was made (by Buttgenbach) to systematize the presentation of data relative to cleavage (for about 100 minerals). New determinative tables, based on optical properties of cleavages, for all cleavable rock-forming minerals (about 200), are presented in the hope that they may be useful to supplement current identification methods. In addition, stereographic projections, on the plane of the cleavage considered, are presented in all cases (about 100) where the normal to the cleavage is inclined more than 5° to any principal optical direction.

HYDROTHERMAL DEPOSITS IN THE SPECIMEN MOUNTAIN VOLCANICS, COLORADO

ERNEST E. WAHLSTROM

Thrust fault zones in the Specimen Mountain volcanics have provided channelways along which post-volcanic hydrothermal solutions moved. Deposition in the faults and replacement of adjacent favorable layers in pyroclastics and flows has produced extensive deposits of jasper and common opal. Associated with the deposits are numerous geodes containing onyx, agate, and platy calcite.

The mineralizing solutions probably came from depth and are related to the magma which was the source of the Specimen Mountain volcanics. However, considerable time elapsed between the extrusion of the volcanics and the deposition from solutions.

THE CHROME MICAS

D. R. E. WHITMORE

The literature of the chrome-micas is reviewed. Methods of separation of pure chrome-mica are outlined and a new analysis of fuchsite from Pointe du Bois, Manitoba, is presented with eleven analyses compiled from the literature, from widely separated localities. The analyses are discussed from a structural point of view after the manner of Stevens, and the relationship of fuchsite to mariposite, and mariposite to alurgite is examined.

Results of an investigation of the paragenetical relationships of chrome-mica are set forth. A review of the literature and study of thin and polished sections suggest a close genetic relationship of chrome-mica to ferruginous carbonate, and also to gold in gold bearing quartz veins. Spectroscopic study suggests that traces of chromium are present in the vein minerals of the Hollinger mine.

New optical data on both mariposite and fuchsite specimens are presented.

UNIT CELL OF DICKINSONITE

C. W. WOLFE

A Weissenberg study has been made of analyzed dickinsonite from Poland, Maine. Rotation, 0-layer-line, and 1-layer-line pictures were about [010], and rotation and 0-layer-line pictures were taken about [001]. The results obtained are: $a_0 = 16.70$ Å, $b_0 = 9.95$ Å, $c_0 = 24.69$ Å, $\beta = 104°41'$; $a_0:b_0:c_0 = 1.695:1:2.507$; space group is $C_{2h}^6 - C_{2/c}$. Probable contents of unit cell: $4[H_2Na_6Mn_{14}(PO_4)_{12} \cdot H_2O]$. Calculated specific gravity $= 3.438$. Measured specific gravity: Poland—3.38, Branchville—3.41.

On two Poland crystals the following forms were found in good position as referred to the structural lattice: $c\{001\}$, $m\{110\}$, $d\{102\}$, $t\{302\}$, $j\{401\}$, $D\{\bar{1}02\}$, $E\{\bar{3}04\}$, $F\{\bar{1}01\}$, $H\{\bar{2}01\}$, $P\{\bar{1}11\}$. The structural elements do not correspond with those of Brush and Dana, derived from Branchville material. The transformation formula, Brush and Dana to structure, is: $\bar{1}00/010/102$. This is but approximate, since Brush and Dana considered their morphological studies to be inadequate. That the Poland dickinsonite is the same as the Branchville material is indicated by the analyses and by identical powder pictures obtained in this study.